

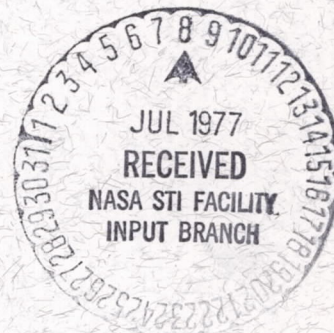
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A COST-BENEFIT EVALUATION OF THE LANDSAT FOLLOW-ON OPERATIONAL SYSTEM

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OF THE LANDSAT FOLLOW-ON OPERATIONAL SYSTEM
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A COST-BENEFIT EVALUATION
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March 1977

Prepared by

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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PREFACE

In conjunction with the Landsat program, NASA has been continually assessing the benefit potential of remote sensing. This report presents the results of the most recent analysis of the projected benefits for an operational Landsat Follow-on system and its related costs. Only benefits to the United States are accumulated, and out of those only the applications for which the technical capability has been demonstrated and the benefits are quantifiable. The analysis shows a dominant economic advantage in favor of the Landsat Follow-on System. The resulting present worth benefit-cost ratio is at least four and possibly as high as nine.

This study has been a continuing, many faceted effort carried out over the past three to four years. Personnel at Goddard Space Flight Center gradually assumed responsibility for the technical direction of the work as it became more and more focused on the Landsat Follow-on systems analysis. The Goddard efforts were ably supported by personnel of the Earth Observations Division at Johnson Space Center and by two principal contractors, ECON, Inc. and General Electric's Valley Forge Space Center.

At Goddard, Charles Buffalano, Ahmed Meer, and Michael Rosenzweig made the main contributions to the methodology and organization of the report. Important support came from Vincent Salomonson and Nicholas Short in the areas of hydrology and petroleum and mineral exploration respectively. The system definition team which determined costs was led by Joseph Schulman, with Thomas Lynch directing the data systems study. Overall direction and guidance of the Landsat Follow-on project at Goddard was the responsibility of William Stroud.

The ECON work under the direction of Klaus Heiss was carried out by John Andrews, Robert Fisch, Keith Lietzke, and Francis Sand.

The GE efforts were directed by Kent Stow on both the data systems design and the study of crop forecast accuracy. John Barker of Goddard supervised the latter effort.

William Stoney, Jr., Landsat Follow-on Program Manager, and Thomas Campbell, Deputy Director Resources Analysis of NASA Headquarters, were helpful in their review of the initial draft of September 1976. Changes to the initial draft have incorporated some recent work. The main additions have been refinements of the program costs, the General Electric study, and a sensitivity analysis of the agriculture model. Petroleum and mineral benefits were reviewed and only slightly modified. The preparation of this final version was the responsibility of Ahmed Meer.

A COST-BENEFIT EVALUATION
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ABSTRACT

This report investigates the major benefits that can be quantified of an operational Landsat Follow-on System. Benefit areas studied include agriculture, petroleum and mineral exploration, hydrologic land use, water resources management, forestry, land use planning and monitoring, and soil management. The annual quantified benefits are in the range of \$420 to \$970 million (FY 1976 dollars).

The operational system sized to achieve the quantified benefits involves a single orbiting satellite with a back-up satellite in launch readiness. The ground system includes a basic processing system which feeds information to three user systems - one for agriculture, one for hydrologic land use, and a third for all other users serviced by the EROS Data Center. The resulting present worth benefit cost ratio is at least 4 (four) with a reasonable likelihood of exceeding 9 (nine). This benefit cost ratio is evaluated for an infinite time horizon at the OMB discount rate of 10 percent.

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A COST-BENEFIT EVALUATION OF THE LANDSAT FOLLOW-ON OPERATIONAL SYSTEM

1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

This volume presents the results of benefit and cost studies for a Landsat Follow-on System. The study was directed by Goddard Space Flight Center with ECON, Inc. and General Electric Corp. providing significant support in the areas of economic benefit analyses and data system trade-off studies respectively. The major conclusion of our studies is that the system benefit cost ratio is in the range of 4 to 9 with the benefits and costs discounted at 10 percent (OMB Circular A-94) and computed for an infinite time horizon. Table 1.1 presents an overview of the discounted benefits by application and the corresponding system and user costs. The costs are separated into the space and data management system common to all users and the unique user data subsystems. The basis for the benefits and costs in Table 1.1 are further detailed below.

Table 1.1

Present Value of the Benefits and Costs of the Landsat Follow-on System
(FY 76 Dollars Discounted at 10%)

Systems and Users	Benefit (\$ Million)	Cost (\$ Million)
Space and Data Management Systems	--	342
Agricultural Crop Information	1,705 - 3,370	55
Hydrologic Land Use	128	10
Petroleum-Mineral Exploration	202 - 819	122
Water Resources Management	75 - 237	
Forestry	41	
Land Use Planning-Monitoring	87 - 278	
Soil Management	29 - 52	530
Total (rounded)	2,260 - 4,920	
Benefit Cost Ratio = 4.3 - 9.3		

It should be noted that the quantitative estimates of benefits in the various economic and public sectors are limited to currently developed or developing uses of the satellite imagery. Since the Landsat technology is continuing to grow in its applications the quantitative benefit estimates and the corresponding benefit cost ratios are believed to be conservative.

The basic Landsat Follow-on System includes both a Multi-Spectral Scanner (MSS) and a Thematic Mapper (TM) on board the Multi-mission Modular spacecraft. The operational system concept is a single orbiting satellite providing a 16-day periodic coverage. A backup spacecraft in launch readiness is included to satisfy the continuity of service requirements of an operational system.

1.2 SUMMARY OF BENEFITS ANALYSIS

The annual economic benefits of each application are listed in Table 1.2. It is seen that agriculture dominates with petroleum and mineral exploration being the second most important. Benefits on the order of or larger than some of those listed in Table 1.2 have not been included due to the relatively strict criteria followed in this study. Benefits have been included only where (i) a definite need for the information has been identified, (ii) a mechanism for disseminating the information has been defined, (iii) a technical capability can be quantified, and (iv) a defensible method of evaluating the economic worth has been developed. For example, benefits of range management are not included in Table 1.1 or 1.2 because a satisfactory data system was not established. Some examples of potential benefits not included are identified in the corresponding applications or in the final chapter called "Non-Quantified Benefits."

The rate of adoption of Landsat technology, and hence the rate of achieving the potential annual benefits, cannot be precisely estimated. We have assumed that 50 percent of the estimated potential benefits will be achieved within the first year that the Landsat system becomes available; 80 percent of the potential benefits will be achieved three years after the system becomes available, and 95 percent of the potential benefits obtained three years after that. For petroleum and mineral it is assumed that the benefits last only 10 years. This is shown schematically in Figure 1.1. The reductions in yearly benefits beyond 1991 reflect the decline in Petroleum-Mineral Exploration benefits. The infinite time horizon benefits of Table 1.1 are based on the phase in assumption displayed in Figure 1.1.

● Agriculture Benefits

A major effort in Landsat technology and economic analysis has been in agriculture. The agriculture benefits quantified in this volume are net social benefits resulting from the value of improved crop forecast information on foreign

Table 1.2

Annual Benefits of Landsat Follow-on
(Millions of FY 76 Dollars)

	Benefits
Agricultural Crop Information	294 - 581
Petroleum-Mineral Exploration	64 - 260
Hydrologic Land Use	22
Water Resources Management	13 - 41
Forestry	7
Land Use Planning and Monitoring	15 - 48
Soil Management	5 - 9
	420 - 968

crop production to U.S. consumers and producers. These projected benefits are based on dynamic econometric models that evaluate the effects of improved information on the global agricultural system with emphasis on the wheat market.

The input to the economic model is the system's accuracy or technical capability. Early estimates of accuracy were based on the 90/90 LACIE "at harvest" accuracy. Recent work by GSFC and General Electric working with the LACIE Project in the so-called Sigma Squared study has more precisely defined the Landsat Follow-on accuracy with the Thematic Mapper resolution. This study, based on LACIE blind site data and simulated Thematic Mapper, shows that the Thematic Mapper will do better world-wide than the LACIE goal at harvest of 90/90.

The agriculture benefit shown in Table 1.2 is based on the LACIE system performance criteria of 90/90 at harvest. The value of \$294 million per year benefit in Table 1.2 is the most likely value; the Sigma Squared analysis confirmed this result actually increasing this most likely value by about \$20 million per year. The upper value of \$581 million per year is based on a more optimistic assumption of the economic and technical parameters. Chapter 3 discusses these results in detail and includes some selected sensitivity analyses of the agriculture model, the Landsat Follow-on System technical capability with the Thematic Mapper, the statistical modeling of the current forecasting system, and the most recent refinements in the global agriculture model resulting in an "integrated" production-distribution model.

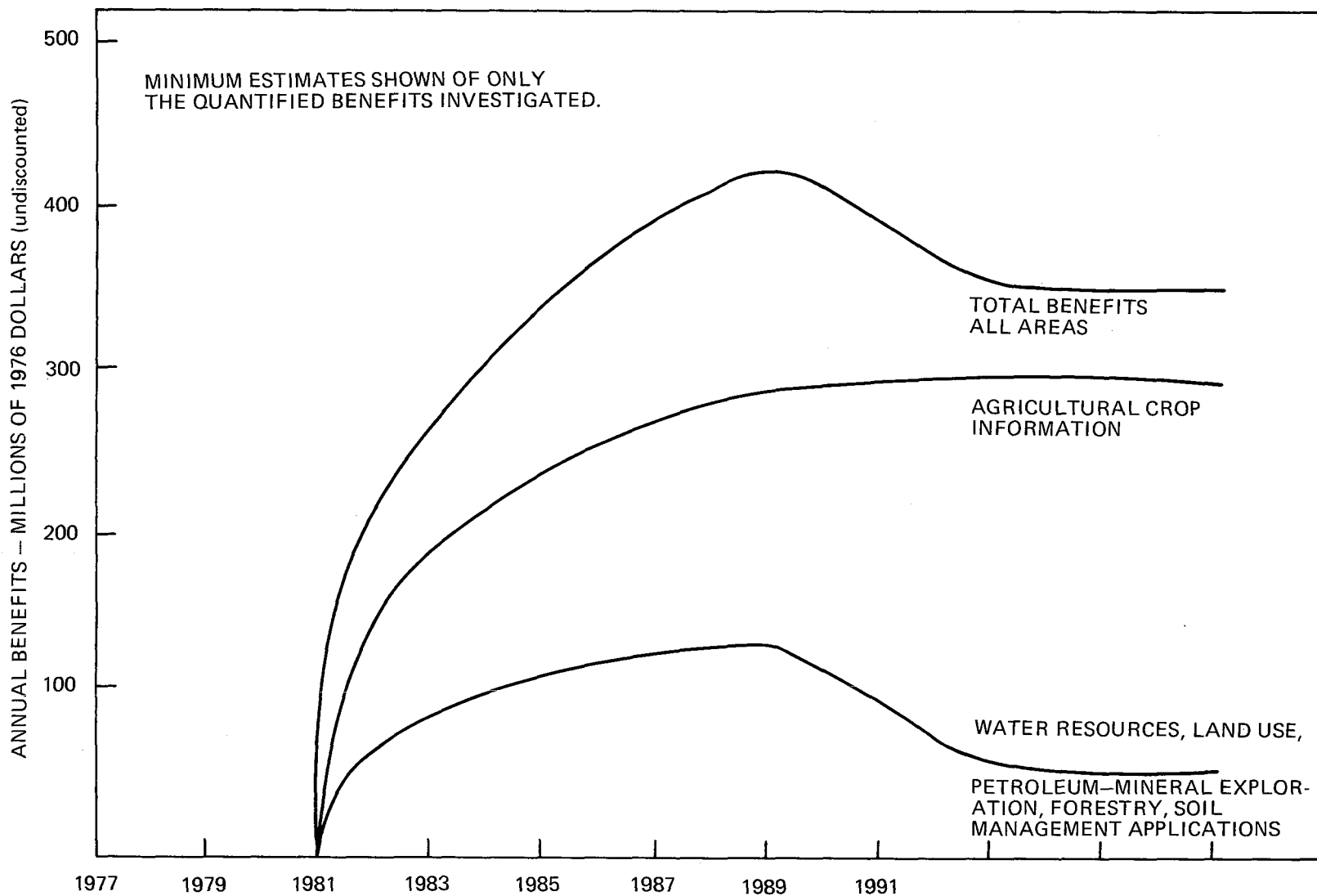


Figure 1.1. Benefit Stream of Landsat Follow-on System with the Thematic Mapper

- Petroleum and Mineral Exploration Benefits - The benefits result from exploration cost savings to United States producers. Annual benefits are estimated between \$64 to \$260 million per year in 1976 dollars. The present worth of these benefits is \$202 to \$819 million. The marginal costs of processing the data from a product tape are incurred at the EROS Data Center but subsequently recovered from the users. This view is based on the assumption that oil and mineral companies will incur only small additional recurring costs of processing beyond what they currently spend to reduce similar aircraft and Landsat 1 and 2 data. Furthermore, there should be only small non-recurring costs since most equipment and training costs will have been incurred to use MSS data from earlier Landsat missions.

The very wide benefit range reflects large uncertainties in many of the variables in the estimate. Unlike the agricultural benefits which are based on a sophisticated econometric model, the oil and mineral benefits are based completely on the judgments of selected experts. There are major uncertainties in the size of the global exploration market and the likely impact of the technology which cannot be resolved at this time.

Finally these exploration benefits disappear after roughly a ten-year period of exploitation. The length of this period is conjectural but it is based on the observation that deposits susceptible to a new technology are found quickly so that productivity is initially high. After the more obvious finds are made the process becomes less productive.

- Hydrologic Land Use - Chapter 5 shows that by reducing the cost of surface cover maps, annual cost savings exceeding \$22 million could be realized. Beneficiaries are identified as federal, regional and local agencies and in addition some special purpose water resource programs. In many cases these benefits could be reinvested in extending or improving the work of the agencies involved, resulting in some further benefits which have not been included in the estimates.
- Land Use Planning Benefits - Land use data is required by federal, state and regional agencies. Chapter 8 estimates these data requirements which are in addition to the data requirements of the other applications. To obtain the current level of land use planning data the Landsat Follow-on System would save \$15 to \$48 million in costs. This cost savings is over that of an airborne surveillance system, the best alternative technique. No special user costs are identified in this application, since this user community already has the capability of processing aircraft data.

- Water Resources Management - Annual benefits of \$13 to \$41 million from more irrigation water and hydropower are expected based on improved management of impounded water due to better information on river basin snow cover. Chapter 6 discusses these applications.
- Forestry and Soil Management - Annual benefits of at least \$7 million are forecast in Chapter 7 by using Landsat information to improve Forest Service timber inventories and then using this improved inventory data to make better tree planting and harvesting decisions.

Annual benefits of \$5 to \$9 million are also estimated from cost savings in the preparation of soil base maps in Chapter 9. Further benefits from detecting soil loss or nutrient deficiencies are identified but not quantified.

- Non-Quantified Benefits - Chapter 10 discusses the four benefit areas of rangeland management, crop pest management, construction siting and global environmental monitoring. Benefits in these areas have not been included because they did not satisfy the criteria of Section 1.2.

1.3 SYSTEM COSTS

The costs of an operational Landsat Follow-on System were developed by Goddard Space Flight Center supported by data system trade-off studies by General Electric Corporation. The overall system and the corresponding costs are described in detail in Chapter 2. The components of the system for cost purposes may be subdivided as:

- Space Segment
- Basic Processing System
- Agriculture User System
- Hydrologic Land Use System
- EROS Data Center

Table 1.3 shows the first ten years of costs of each subsystem and the projected present worth at the 10 percent discount rate for an infinite horizon.

Table 1.3

Landsat Follow-on System Costs
(Millions of FY 76 Dollars)

	Undiscounted Costs											Present Worth TOTAL
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	...	
Space System	4	32.8	74.1	56.5	33.4	25.5	29.1	9.1	4.5	12.5	...	220
	3 year cycle											
Ground System	Constant Recurring Costs*											
1. Basic Processing System	0.0	9.9	13.8	14.0	17.1	11.8	11.8	11.8	11.8	11.8	...	122
2. Agriculture Use System	0.0	1.6	3.7	3.7	8.1	6.5	6.5	6.5	6.5	6.5	...	55
3. Hydrologic Land Use System	0.0	0.5	1.3	1.2	1.5	1.0	1.0	1.0	1.0	1.0	...	10
4. EROS Data Center	0.0	1.0	6.0	6.0	16.0	16.0	16.0	16.0	16.0	16.0	...	122
Subtotal	0.0	13.0	24.8	24.9	42.7	35.3	35.3	35.3	35.3	35.3	...	310
TOTAL	4	45.8	98.9	81.4	76.1	60.8	64.4	44.4	39.8	47.8	...	530
*Every 10 years a nonrecurring cost of equipment replacement occurs. The replacement period is 2 years. The first replacement is scheduled in 1990 - 1991. The Basic Processing system replacement costs \$25 million, the Agriculture system costs \$7.5 million, the Hydrologic system \$2.5 million and the EROS Data Center \$9.2 million.												

The space segment includes all the costs of spacecraft acquisition, launching and maintenance of an operational system launched in 1981 and utilizing shuttle launch and retrieval beyond 1984. The maintenance and operation costs include acquisition of additional spacecraft, shuttle servicing and refurbishment of shuttle retrievals. The basic processing system includes the NASA tracking and data acquisition system and data management system to produce a generally available archival tape. Every ten years costs for replacing worn out equipment are included resulting in a 10-year cycle. These costs streams are detailed in Chapter 2.

The user costs include facilities for special processing of the archival tape to obtain management information.

The marginal agriculture costs of \$55 million are to build and maintain a data processing facility for the United States Department of Agriculture (USDA). The costs were derived using GSFC/General Electric Study data. This facility would produce foreign crop production estimates. Public announcements of the improved estimates automatically produce the production and distribution benefits through the market place.

The Hydrologic Land Use cost of \$10 million includes the initial construction of facilities by the Corps of Engineers and the subsequent operation and maintenance costs with equipment replacement every 10 years. Again, these are GSFC/General Electric study results.

The EROS Data Center costs include augmentation of equipment and software at the physical facility at Sioux Falls and the costs of operation and maintenance of the facility as obtained from the GSFC/General Electric Studies. The Center is expected to fill the needs of all the other applications except the USDA and the Hydrologic Land Use data.

The Landsat Follow-on System costs estimates should be realistic since they are based on past experience of very similar systems. A small contingency has been included to provide for some growth. The \$530 million present value of the total cost compared to the corresponding benefit of \$2.3 to \$4.9 billion indicates a dominant economic advantage in favor of the Landsat Follow-on system.

2. SYSTEM COSTS

2.1 INTRODUCTION

The Landsat Follow-on system consists of two parts, a Space Segment and a Ground Data Management System. Costs of each part are summarized below in terms of non-recurring costs and the recurring costs of operations and maintenance. The basis of these costs are developed at GSFC, with some support from the Landsat Follow-on data systems studies carried out by General Electric, Valley Forge. The annual undiscounted and discounted (10 percent) cost streams are presented for both the Space Segment and the Data Management System.

Our approach has been to closely tie the benefits analyses to the technical performance characteristics of the space and data systems to insure somewhat of an optimal balance between the system's performance and the benefits. As a result, the system is no larger and its capabilities, such as in the number of Thematic Mapper scenes processed per day, are not more extensive than necessary to achieve the identified economic benefits.

The system costs summarized here include all systems elements from sensing to the extraction and reporting of the information which is utilized to obtain the quantitative benefits determined for the various applications. Thus, the costs incurred by the users of the data are included, to the extent that it has been possible to identify and isolate them. As with the economic benefits the present worth costs are given for 10% discount rate, to an infinite horizon and total \$530 million (FY 76 dollars).

2.2 SPACE SEGMENT COSTS

The Space Segment provides a minimum of three years global observations and is designed to extend indefinitely into the shuttle era. The extension of operations into the shuttle era is reflected in reduced costs by utilizing shuttle retrieval and Space Segment refurbishment capabilities.

The initial system provides a 16-day periodic coverage with a single satellite in orbit. A second Space Segment is maintained in a state of launch readiness in the event of a premature failure of the first unit.

The initial Space Segment for the pre-shuttle era has the following components:

1. Two NASA Multi-Mission Modular Spacecraft (MMS) with associated Mission Uniques equipped to use the Tracking and Data Relay Satellite System (TDRSS).

2. Two instruments per spacecraft, one Multi-Spectral Scanner (MSS) and one Thematic Mapper (TM).
3. Two Delta 3910 launch vehicles.

Figure 2.1 shows the components of a single space unit for the Space Segment. The Space Segment costs follow the breakdown in Figure 2.1. The Mission-Unique Subsystems refers to all the other hardware not part of the instruments, MMS, or launch vehicle. For example, the solar array and the TDRSS antenna are part of the Mission-Unique subsystems.

The initial launch of the Landsat Follow-on is in 1981 on a Delta Launch vehicle. The shuttle era begins with a launch in 1984 from the Western Test Range (WTR). The post-shuttle phase involves a one-time acquisition of a third spacecraft called the Augment Unit, which is the same space unit as shown in Figure 2.1, except for the launch vehicle. Retrieval and refurbishment continue every three years. In the shuttle era, the plan is one Space Segment in orbit, one Space Segment in launch readiness, and one Space Segment being refurbished on the ground.

The Space Segment costs are listed in Table 2.1 for the first eight years. The non-recurring costs are separated into the initial Space Segment and the Augment Space Segment. Program management costs include integration and test and an allowance for cost growth for the Space Segment. The recurring costs are the civil service costs related to the Space Segment and the shuttle era refurbishment costs which have a three-year periodicity. The costs shown in Table 2.1 are undiscounted and hence the totals in the right side column are only for the non-recurring costs.

The first 35 years of the Space Segment cost stream is given in Table 2.2. Both undiscounted and discounted (10 percent) cost streams are presented in Table 2.2. The present worth of this cost stream accumulated to an infinite horizon is \$220 million (FY 76 dollars).

2.3 DATA MANAGEMENT SYSTEM COSTS

The Data Management System is an end-to-end system, including both the basic NASA ground processing system and the user data processing subsystems and is shown in Figure 2.2. Care has been taken to allocate data processing costs commensurate with the information requirements identified in the benefits assessment. Thus, the basic NASA ground system has been sized to process on the average of 200 MSS and 100 TM scenes per day. Similarly, the user subsystems for Agriculture, Hydrology, and the EROS Data Center (EDC) are sized to handle the number of scenes required to produce the benefits described elsewhere. The initial non-recurring costs of the ground system include the opera-

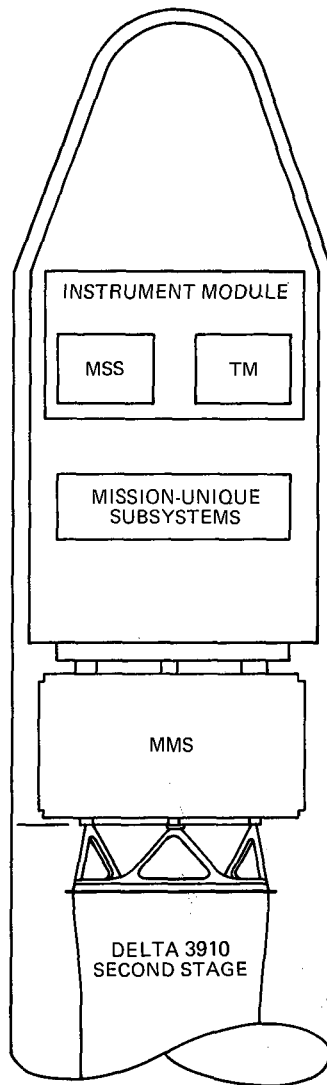


Figure 2.1. Configuration of Initial Space Unit in Landsat Follow-on

Table 2.1

Space Segment Undiscounted Costs
(Millions of FY 76 Dollars)

Cost Components	Year								Total
	77	78	79	80	81	82	83	84	
Non-Recurring Initial Segment									
Instrument	4	15	27	18	2	-	-	-	66
Mission Unique & Prog. Mgt.	-	6	25	31	13	4	3	-	82
MMS	-	11	12	2	-	-	-	-	25
Launch Vehicle	-	0	9	4	-	-	-	-	13
Sub-Total	4	32	73	55	15	4	3	-	186
Augment Unit									
Instrument	-	-	-	-	7	7	5	-	19
Mission Unique & Prog. Mgt.	-	-	-	-	6	6	4	-	16
MMS	-	-	-	-	4	4	4	-	12
Sub-Total	-	-	-	-	17	17	13	-	47
Recurring									
Civil Service Cost	-	0.8	1.1	1.5	1.4	0.5	1.1	1.1	N/A*
Refurbishment	-	-	-	-	-	4	12	8	N/A*
Annual Totals	4.0	32.8	74.1	56.5	33.4	25.5	29.1	9.1	N/A*
*Not Applicable									

Table 2.2

Space Segment Cost Stream
(Millions of FY 76 Dollars)

Year	Initial Unit	Augment Unit	Civil Svc.	Refurb.	Total	Annual Present Worth	Accrued PW
1977	4.0	0.0	0.0	0.0	4.0	3.6	3.6
1978	32.0	0.0	0.8	0.0	32.8	27.1	30.7
1979	73.0	0.0	1.1	0.0	74.1	55.6	86.4
1980	55.0	0.0	1.5	0.0	56.5	38.5	125.0
1981	15.0	17.0	1.4	0.0	33.4	20.7	145.7
1982	4.0	17.0	0.5	4.0	25.5	14.3	160.1
1983	3.0	13.0	1.1	12.0	29.1	14.9	175.0
1984	0.0	0.0	1.1	8.0	9.1	4.2	179.3
1985	0.0	0.0	0.5	4.0	4.5	1.9	181.2
1986	0.0	0.0	0.5	12.0	12.5	4.8	186.0
1987	0.0	0.0	1.1	8.0	9.1	3.1	189.2
1988	0.0	0.0	0.5	4.0	4.5	1.4	190.6
1989	0.0	0.0	0.5	12.0	12.5	3.6	194.2
1990	0.0	0.0	1.1	8.0	9.1	2.3	196.6
1991	0.0	0.0	0.5	4.0	4.5	1.0	197.7
1992	0.0	0.0	0.5	12.0	12.5	2.7	200.4
1993	0.0	0.0	1.1	8.0	9.1	1.8	202.2
1994	0.0	0.0	0.5	4.0	4.5	0.8	203.0
1995	0.0	0.0	0.5	12.0	12.5	2.0	205.1
1996	0.0	0.0	1.1	8.0	9.1	1.3	206.4
1997	0.0	0.0	0.5	4.0	4.5	0.6	207.0
1998	0.0	0.0	0.5	12.0	12.5	1.5	208.6
1999	0.0	0.0	1.1	8.0	9.1	1.0	209.6
2000	0.0	0.0	0.5	4.0	4.5	0.4	210.1
2001	0.0	0.0	0.5	12.0	12.5	1.1	211.2
2002	0.0	0.0	1.1	8.0	9.1	0.7	212.0
2003	0.0	0.0	0.5	4.0	4.5	0.3	212.3
2004	0.0	0.0	0.5	12.0	12.5	0.8	213.2
2005	0.0	0.0	1.1	8.0	9.1	0.5	213.8
2006	0.0	0.0	0.5	4.0	4.5	0.2	214.0
2007	0.0	0.0	0.5	12.0	12.5	0.6	214.7
2008	0.0	0.0	1.1	8.0	9.1	0.4	215.1
2009	0.0	0.0	0.5	4.0	4.5	0.1	215.3
2010	0.0	0.0	0.5	12.0	12.5	0.4	215.8
2011	0.0	0.0	1.1	8.0	9.1	0.3	216.1
Infinite Horizon							220.0

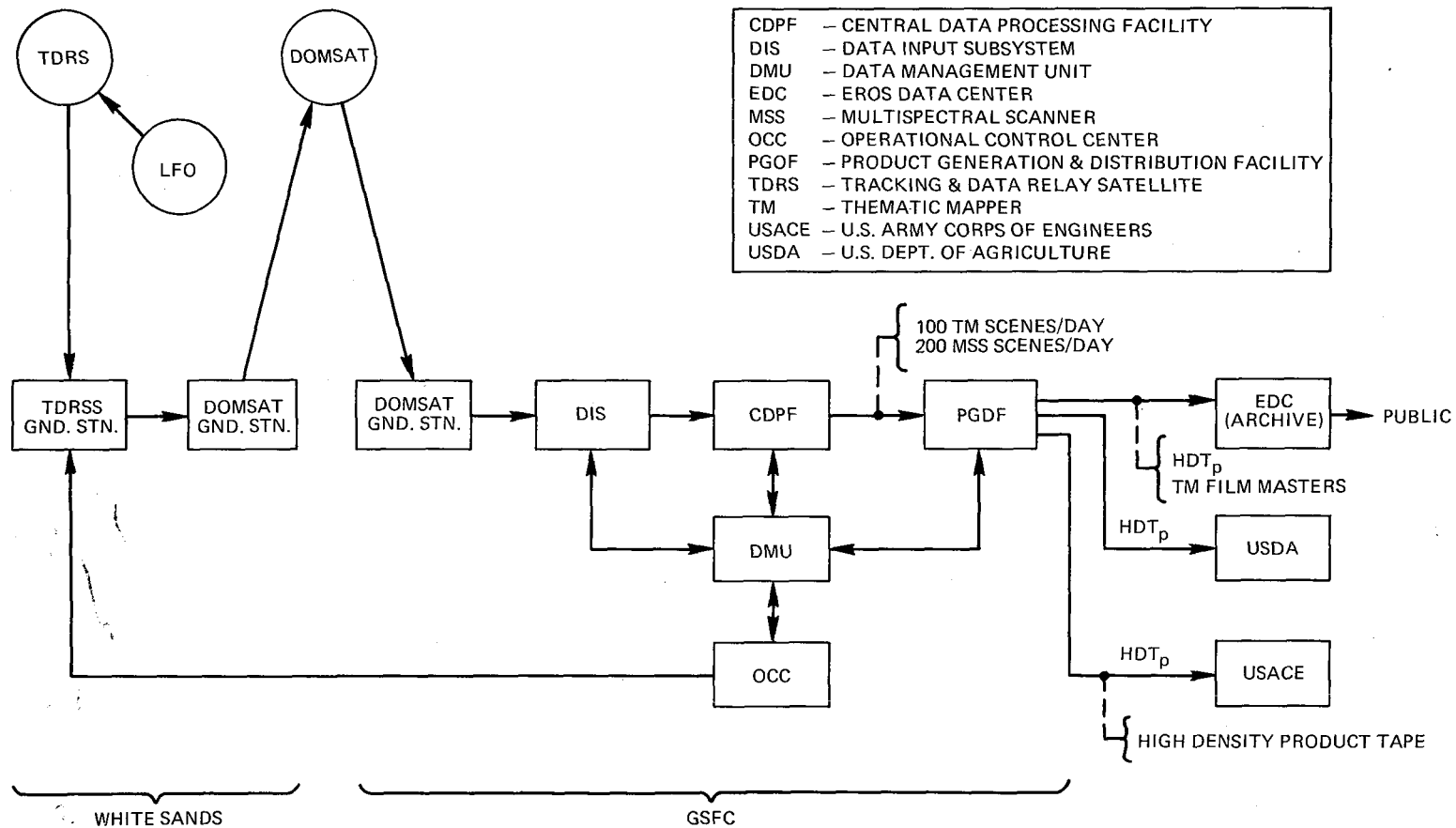


Figure 2.2. Landsat Follow-on End-to-end Data System

tions and hardware costs together with additional costs for overall system engineering and modifications to the Goddard Space Flight Center's direct readout station to receive TM data. Table 2.3 shows these non-recurring costs of the NASA ground system. Also shown in Table 2.3 are the recurring costs of the first eight years. These are for the operation of all the bulk processing facilities and the control center.

Subsequent capital costs are required for refurbishment and replacement of worn-out equipment in the NASA ground system. These costs are approximately 70 percent of the initial non-recurring costs and repeat every ten years. Table 2.4 presents non-recurring costs and recurring costs of the total Landsat ground system for the first 35 years.

The cost streams of the three user subsystems are included in Table 2.4. The annual and accrued present worth discounted at 10 percent is included in Table 2.4 for the first 35 years. For an infinite horizon the total Data Management System cost in 1976 U.S. dollars is \$310 million, with \$120 million for the NASA ground system and \$190 million for the user subsystems described below.

The agricultural capital cost is essentially the development and construction of a crop information extraction facility for the United States Department of Agriculture and the subsequent capital costs are for the regular replacement of worn-out equipment. The recurring cost is for the operation of the facility. These costs are based on GSFC and General Electric's 1976 ground system study.

The 1981 Hydrologic Land Use capital cost is the cost of the initial construction of a single information extraction facility for all users and the subsequent capital costs are for regular replacement of worn-out equipment. The recurring cost is for the operation of the facility. These cost estimates are based on an analysis by General Electric of the ground system configuration required to achieve the benefits.

The EROS Data Center (EDC) capital cost is the cost of augmentation of equipment and software at the physical facility at Sioux Falls to handle the TM data tapes. The recurring cost is for the operation of the facility. As with Agriculture these costs are based on the GSFC and GE study.

Table 2.3

Basic Ground Processing System
(Millions of FY 76 Dollars)

Cost Components	Year								Total
	77	78	79	80	81	82	83	84	
Non-recurring									
Tracking and Data Acquisition	-	1.0	2.0	2.0	1.0	-	-	-	6
Data Management	-	4.8	10.7	10.7	3.8	-	-	-	30
Construction of Facility	-	3.0	-	-	-	-	-	-	3
Civil Service Cost	-	1.1	1.1	1.3	0.5	-	-	-	4
Sub-Total	-	9.9	13.8	14.0	5.3	-	-	-	43
Recurring									
Tracking and Data Acquisition	-	-	-	-	1.5	1.5	1.5	1.5	N/A*
Data Management	-	-	-	-	8.2	8.2	8.2	8.2	N/A*
Civil Service Cost	-	-	-	-	2.1	2.1	2.1	2.1	N/A*
Sub-Total	-	-	-	-	11.8	11.8	11.8	11.8	N/A*
Annual Totals	-	9.9	13.8	14.0	17.1	11.8	11.8	11.8	N/A*
*Not Applicable									

Table 2.4

Data Management System Cost Stream
(Millions of FY 76 Dollars)

Year	Capital (NASA)	Recur (NASA)	Ag.	Hyd.	EDC	Total	Annual Present Worth	Accrued PW
1977	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1978	9.9	0.0	1.6	0.5	1.0	13.0	10.7	10.7
1979	13.8	0.0	3.7	1.3	6.0	24.8	18.6	29.3
1980	14.0	0.0	3.7	1.2	6.0	24.9	17.0	46.3
1981	5.3	11.8	8.1	1.5	16.0	42.7	26.5	72.8
1982	0.0	11.8	6.5	1.0	16.0	35.3	19.9	92.8
1983	0.0	11.8	6.5	1.0	16.0	35.3	18.1	110.9
1984	0.0	11.8	6.5	1.0	16.0	35.3	16.4	127.4
1985	0.0	11.8	6.5	1.0	16.0	35.3	14.9	142.3
1986	0.0	11.8	6.5	1.0	16.0	35.3	13.6	155.9
1987	0.0	11.8	6.5	1.0	16.0	35.3	12.3	168.3
1988	0.0	11.8	6.5	1.0	16.0	35.3	11.2	179.6
1989	0.0	11.8	6.5	1.0	16.0	35.3	10.2	189.8
1990	12.5	11.8	10.3	2.3	21.0	57.9	15.2	205.0
1991	12.5	11.8	10.2	2.2	20.2	56.9	13.6	218.6
1992	0.0	11.8	6.5	1.0	16.0	35.3	7.6	226.3
1993	0.0	11.8	6.5	1.0	16.0	35.3	6.9	233.3
1994	0.0	11.8	6.5	1.0	16.0	35.3	6.3	239.7
1995	0.0	11.8	6.5	1.0	16.0	35.3	5.7	245.4
1996	0.0	11.8	6.5	1.0	16.0	35.3	5.2	250.7
1997	0.0	11.8	6.5	1.0	16.0	35.3	4.7	255.5
1998	0.0	11.8	6.5	1.0	16.0	35.3	4.3	259.8
1999	0.0	11.8	6.5	1.0	16.0	35.3	3.9	263.7
2000	12.5	11.8	10.3	2.3	21.0	57.9	5.8	269.6
2001	12.5	11.8	10.2	2.2	20.2	56.9	5.2	274.9
2002	0.0	11.8	6.5	1.0	16.0	35.3	2.9	277.8
2003	0.0	11.8	6.5	1.0	16.0	35.3	2.6	280.5
2004	0.0	11.8	6.5	1.0	16.0	35.3	2.4	283.0
2005	0.0	11.8	6.5	1.0	16.0	35.3	2.2	285.2
2006	0.0	11.8	6.5	1.0	16.0	35.3	2.0	287.2
2007	0.0	11.8	6.5	1.0	16.0	35.3	1.8	289.1
2008	0.0	11.8	6.5	1.0	16.0	35.3	1.6	290.7
2009	0.0	11.8	6.5	1.0	16.0	35.3	1.5	292.2
2010	12.5	11.8	10.3	2.3	21.0	57.9	2.2	294.5
2011	12.5	11.8	10.2	2.2	20.2	56.9	2.0	296.5
Infinite Horizon								310.0

3. AGRICULTURE CROP INFORMATION

3.1 INTRODUCTION

The principal thrust of the NASA/GSFC studies for the Landsat Follow-on has been to determine the economic benefits and systems performance requirements for remote sensing of foreign agriculture. The early economic analyses by Bradford and Kelejian (1974) extending the work of Hayami and Peterson (1972) had shown that the net social benefits resulting from more accurate and timely forecasts of the production of wheat, corn, and other major crops were very large. Similarly, the experience with Landsat 1 and 2 had demonstrated the great potential of multispectral remote sensing for determining crop production; a major experiment, the Large Area Crop Inventory Experiment (LACIE) was established to determine how accurately the production of wheat could be forecast. The Landsat Follow-on agriculture benefits are based on the "integrated" ECON model (Andrews, November 1976). This model is a decision theoretic normative model, it uses dynamic programming to solve the optimization problem. The integrated model combines the two agriculture benefits of distribution (Andrews, June 1976) and production (ECON 1976) that were treated separately in the previous work. Each of these reports is well documented; consequently, this chapter presents a heuristic explanation of the benefits from improved accuracy.

To capture the U.S. benefits without a detail modeling of each foreign country's agriculture relationship to the U.S. the ECON models aggregate the rest of the world (ROW or Rest of World) into one trading unit, with U.S. as the other unit. Thus, a key technical issue in establishing the benefits is how accurate Landsat forecast of ROW production will be. An equally important input to the models is the current forecast accuracy of ROW production. The investigations carried out in each of these subjects are discussed.

On the Landsat crop forecast accuracy of ROW two approaches are included here:

- a. A simple model of the variation of forecast accuracy with time from pre-planting to post-harvest. This model resulted from a series of investigations based on the LACIE goal of production forecast accuracy at harvest of 90/90 (within 90 percent of true production, 90 percent of the time). The benefit estimates in Andrews (1976) are based on this model.
- b. The second approach was carried out to support this study. It is based on a simulation of LACIE performance and methodology to derive

production forecast accuracy by crop, by country, by month of the economically significant countries - the so-called Sigma Squared study by GSFC-General Electric.

These approaches give similar order of benefits, with the Sigma Squared being about \$20 million higher in wheat. The Sigma Squared results show that the Landsat Follow-on with the Thematic Mapper will do better worldwide than the LACIE goal at harvest of 90/90 (90 percent accuracy, 90 percent of the time).

Section 3.2 summarizes the Landsat agriculture benefits and presents the sensitivity of these benefits to fundamental economic parameters of demand and supply elasticities, interest rates and the technical performance parameters of the current and future information system.

In Section 3.3 the impact of the benefits on various groups in the United States is assessed. This is followed by Section 3.4 which describes the distribution, production and integrated benefit models. The integrated model is an extension of the normative distribution model and eliminates some of the limitations of the production model which was an econometric model. All three models are based on a free market assumption; however, the empirically derived demand and supply elasticities reflect, in an aggregated sense, the effects of policy and other institutional constraints.

Section 3.5 carefully outlines the effort carried out to assess the current crop forecasting information and the analysis to estimate the accuracy of the Landsat information. The Sigma Squared study is summarized in Subsection 3.5.3.

3.2 SUMMARY OF BENEFITS AND SENSITIVITY RESULTS

Landsat Follow-on has been designed to monitor the worldwide production of food and feed crops. Total annual benefits to the United States from improved foreign crop production forecasts are estimated at \$294 million to \$581 million, with the Thematic Mapper capability. These results precede the Sigma Squared study which is summarized in Section 3.5.3. The lower value of \$294 million is the most likely value. This lower value will increase by at least \$20 million using the Sigma Squared performance.

Within the United States, the Department of Agriculture (USDA) publishes crop production forecasts on the major field crops most months until the harvest is completed, and continues to publish production estimates through the end of the year. With regard to most other countries, however, data are not available until harvest time or even later, and in important cases of dubious reliability. Landsat Follow-on offers a practical means of extending the U.S. preharvest fore-

casting system to other countries, yielding large benefits to the United States. The benefits result from making the information publicly available to all countries. Further benefits may accrue if the U.S. crop reporting system can be improved in timeliness or accuracy through Landsat, but no improvement in the U.S. crop reporting system is assumed for purposes of computing the benefits reported here.

Two major classes of benefits arise from the improved world crop forecasts made possible by Landsat Follow-on "distribution" and "production" benefits. Figure 3.1 illustrates how improved information leads to benefits in these two classes. The discussion in subsequent sections is also organized to follow this figure from left to right.

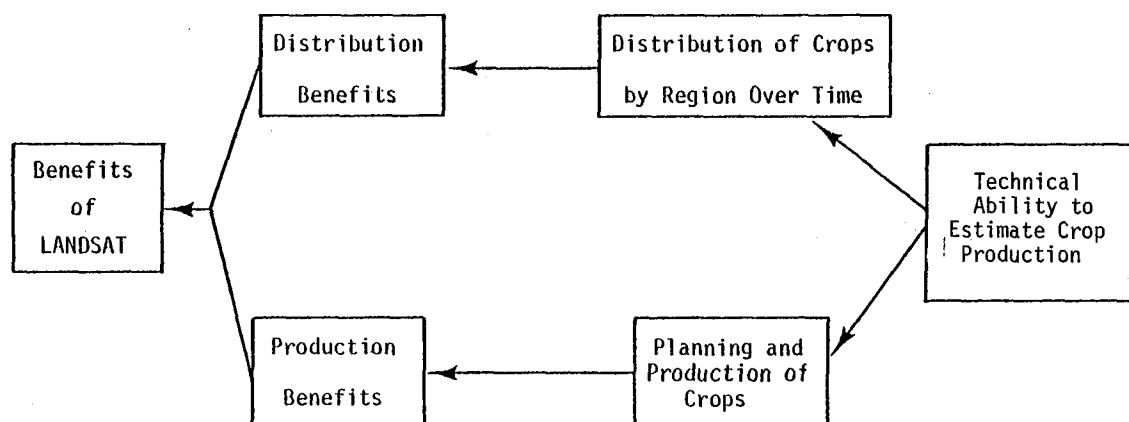


Figure 3.1. How Improved Information Contributes to Agricultural Crop Benefits

Distribution benefits result from distributing crops more efficiently in time and space. The total quantity of crops produced stays the same. What changes is where and when the crops are used. Temporal distribution is achieved by crop storage. Crops are stored or withdrawn in anticipation of future shortages or abundance. Storage is costly, however, in terms of interest costs, physical costs of facilities and maintenance, and spoilage. Interest costs are by far the most significant. Better information permits storage to be used more efficiently and the storage costs to be reduced, while the benefits of storage - steadier consumption and prices - can be increased.

The other type of distribution benefit is one of place rather than time. Commodity trading redistributes the world's agricultural production; the better the

information, the better the redistribution from areas of surplus to areas of need. Improved crop information permits the transportation and related costs to be reduced, while making prices and hence consumption more responsive to regional needs. The mechanism for realizing these gains is the world commodities futures market, and not a special planning agency. Future prices influence storage, withdrawal and trade decisions, and operate in the direction of more even distribution in time and place when the accuracy of production forecasts is improved (Bradford-Kelejian 1974).

We have estimated the magnitude of the annual U.S. distribution benefits; none of the benefits to other nations is included. These benefits are shown under "Distribution Benefits" in Table 3.1, and include \$108 million for wheat alone, and \$227 million for all eight crops that were studied. These benefits are based on an improved estimate of foreign production where improved means the production estimate is less than 10 percent in error at harvest, 90 percent of the time.

Production benefits are the second major source of benefits derivable from improved information. In this set of analyses the total quantity of a crop produced is allowed to change in response to different (improved) information. These changes result from improved decisions that farmers can make with better knowledge of the predicted harvest, or in response to the prices that reflect this better knowledge. At U.S. planting time, which may occur after crops are well underway elsewhere in the world, the farmer can make improved choices of which crops to plant and the acreage to devote to each. This is the major variable he controls. As the season progresses, the farmer can use improved information to determine the appropriate levels of investments to make in irrigation, fertilizer and pesticides; and to determine whether to harvest the crop or plow it under. The planting decision is by far the most important, and is the one selected for modeling. Production information, of course, is mostly significant for crops that are important in world trade and is only one element figuring in production decisions. The modeling work computes only the component of benefit derived from improved information and realized by U.S. producers or consumers.

The benefit appears in the form of more even total production of crops. If forecasts are accurate, more production is encouraged when it is needed, less when it is not, mostly in response to unexpected developments in other regions or of other crops. Conversely, inaccurate forecasts tend to promote or discourage production at the wrong times, crop production is less stable. Since the world's food needs are better served by stable production and stable prices, a benefit results from better forecasts.

Table 3.1

Annual U.S. Benefits from Improved World Crop Information
(Millions of FY 76 Dollars)

Crop	Production Benefit (January 1976)	Distribution Benefit (June 1976)	Integrated Benefits
Wheat	162	108	235*
Oats, Barley, Rye	N.A.	4	4
Corn	N.A.	104	48
Soybeans	N.A.	11	7
Sugar	N.A.	0	0
Potatoes	N.A.	0	0
Total	162	227	294
*Production and Distribution benefits are not completely additive. The \$235 million is based on an integrated evaluation of both effects.			
N.A. = not available.			

It is important to note that the benefit is obtained if the information is published, whether or not every farmer reads the forecasts. The market mechanism adjusts spot and futures prices to reflect the forecasts, and it is the price level that operates to encourage improved decisions.

Table 3.1 shows the benefits anticipated for the Landsat Follow-on system. Production benefits and distribution benefits are shown separately and in combination. The effects are not completely additive, however, so that the "combined" benefits are not always as great as the sum of the separate effects. This is due to the fact that production and distribution effects of improved crop information take place simultaneously.

Total benefits are estimated on the basis of a model that integrates distribution and production effects. This model uses an idealized representation of the process by which successive annual crops of varying size are produced throughout the world and then distributed to consumers at different times and places. It includes modeling of the activities of crop production, inventory management and international trade. The various market agents are classed into producers (farmers), inventory holders, exporters, importers and consumers. The model describes the decision making of these agents and its consequences over an extended time period as a function of available crop information. The integrated

model extends the distribution model to incorporate the production benefits into a single model.

The total benefits that result from this integrated evaluation are shown in the last column of Table 3.1.

The table indicates that wheat and corn are the two crops accounting for nearly all the U.S. benefits from improved world crop information. The reasons are as follows:

1. In the case of oats, barley and rye, and potatoes, little U.S. trade takes place.
2. Soybeans are produced mainly in the U.S., with only a few other countries growing significant amounts of soybeans (Brazil, China) so that world soybean crop data have little impact on U.S. decisions.
3. A major fraction of the sugar traded internationally is covered by various protective agreements. The U.S. is a net importer of sugar, but cannot benefit significantly from world sugar crop data under the existing market arrangements.

The results shown in Table 3.1 reflect the baseline evaluation of the Landsat Follow-on with conservative assumptions as to the technical and economic performance capabilities of the program. These results precede the Sigma Squared analysis. The benefit based on Sigma Squared is shown in Figure 3.2 for wheat. The values shown in Table 3.1 should not be construed as exact point estimates since economic benefit projections have inherent uncertainties. The range of benefits that might result from changes in the assumptions are shown in Table 3.2. Two sets of numbers are shown. The first column shows the baseline benefits and the second shows an upper bound benefit estimate. The baseline benefits result from conservative assumptions on economic and technical performances of the Landsat Follow-on system and the users of that information. For example, if the economic assumptions on the demand for wheat and other crops are changed to reflect risk aversion and nonlinear demand functions the benefits increase. The upper bound column shows a reasonable, but more optimistic, assessment of the benefits of the Landsat Follow-on program. The upper bound reflects a variety of factors that can make the applications of Landsat information in agriculture more valuable than assumed in the baseline assessment. A set of sensitivity analyses involving variations in economic parameters was performed in the case of wheat crop information - using the integrated (combined) model. The results of changes in these key economic parameters are shown in Figure 3.2.

Table 3.2

Likely and Potential U.S. Annual Benefits
from Improved World Crop Information

Crop	Baseline*	Upper Bound
Wheat	235	400**
Other Small Grains	4	4
Corn	48	97**
Soybeans	7	80***
Sugar	0	--
Potatoes	0	--
Total	294	581
*Based on Table 3.1 **Based on Sensitivity Analyses ***Based on U.S. export effects in soybeans due to improved information on other crops worldwide.		

These sensitivity analyses indicate that benefits from improved global wheat crop information vary most widely with changes in the demand parameters. The baseline case assumes demand elasticities for wheat of -0.48 in the United States and -0.16 for the Rest of World. These elasticities were established in the work of Bradford and Kelejian (1974). As the demand elasticities in the Rest of World are increased, the benefits to the United States increase, whereas more inelastic demand for wheat leads to smaller U.S. benefits from improved public crop information. With demand elasticities of -1.0 for the United States and -0.32 for the Rest of World (reasonable estimates of substitution effects between crops are allowed for) the benefits to the United States will be \$479 million.

The next most critical economic parameter is the interest rate. The interest rate is a major cost of storage. With low interest rates inventories can be carried over larger time periods to equalize uncertainties and fluctuations in the supply of crops. Hence at low interest rates improved crop information has less economic value than in the case of high interest rates. By analogy, improved crop information will be of greater value to relatively poor countries (high cost of scarce capital resources). For the United States interest rates for the valuation of investment projects have been assumed to range from 6 percent to 15 percent. At 6 percent, U.S. benefits in wheat are only \$137 million; at 15 percent

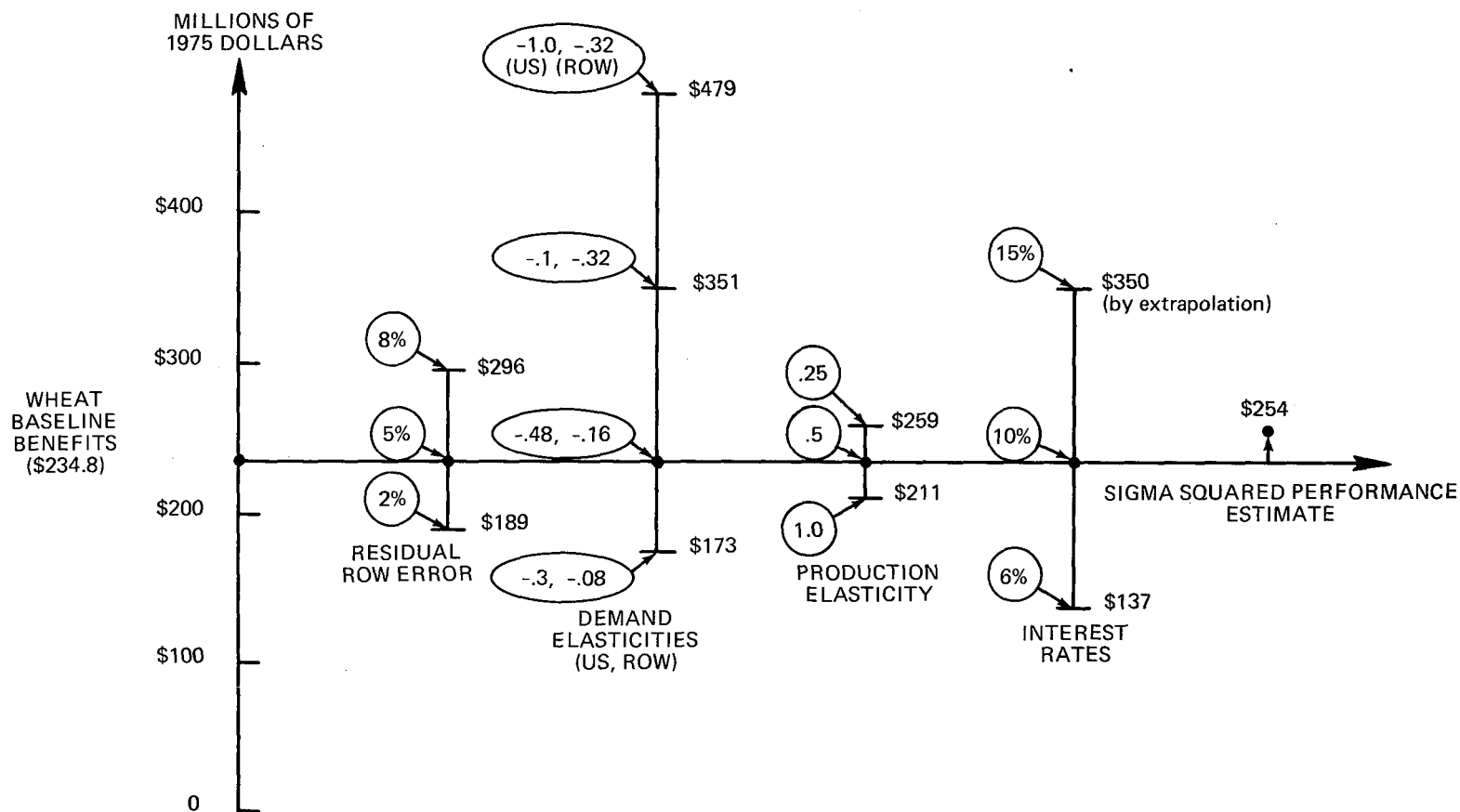


Figure 3.2. Sensitivity of Benefit Estimates (Wheat) to Changes in Key Economic Parameters

U.S. benefits from wheat crop information would be \$350 million. For the evaluation of public (federal) investment projects the "social discount rate" has been set by the Office of Management and Budget at 10 percent, the rate used in the baseline case evaluation.

An opposite effect of interest rates will occur on the net present value of the benefits. Hence, even though the annual benefits are higher with the higher interest rate the net present value of the agriculture benefits may be unaffected by interest rates. On the other hand, increased storage costs will increase the benefits of improved crop information.

The most surprising result of the sensitivity tests is that supply elasticities have relatively little impact on benefit estimates. The less production can respond to changing prices, the larger the benefits from improved crop information. However, varying production elasticities from 0.25 to 1.0 leads to relatively minor variations in the benefits from \$259 million to \$211 million.

Residual error assumptions - i.e., errors carried forward in "final" crop estimates - have some influence on estimated benefits, changing from a low of \$189 million in the case of only a 2 percent residual error in Rest of World crop estimates, to a high of \$296 million with an 8 percent residual error (see Section 3.5.1).

The evaluation of Landsat performance as determined by the Sigma Squared study confirms the annual wheat benefits in the baseline case and in fact increases the benefit from \$234 million to \$254 million. The Sigma Squared study is based on extending LACIE and simulated TM performance data worldwide. The baseline approach was to assume for the rest of the world the LACIE 90/90 goal at harvest and approximate it by a flat and a linearly decreasing segment; the Sigma Squared study develops the time history from LACIE crop calendar data (see Section 3.5.2).

The upper bound of \$400 million in Table 3.2 (taking the range between \$351 to \$479 million) reflects generally higher demand elasticities for wheat in the Rest of World - of about -0.32. The estimate of \$479 million results if the demand elasticities in the United States are similarly higher, -1.0, a quite realistic estimate if substitution of other food crops for wheat is allowed for in the estimation of demand elasticities (Bradford, Kelejian, 1974). The upper bound for corn crop information reflects similar changes in technical and economic assumptions. The upper bound for soybean benefits is based on an assessment of U.S. soybean exports due to improved information on other crops worldwide: if crops in some regions, say east Asia, are generally low and these shortages are discovered in time, U.S. exports of soybeans tend to increase.

In summary, the results using the ECON models project benefits of Landsat Follow-on information in agricultural crop markets to be about \$294 million annually with an upper bound of \$581 million a year by 1985. The sensitivity studies indicate significant positive benefits over a range of fundamental economic assumptions. The Sigma Squared performance results support the ECON benefit projection.

3.3 IMPACT OF BENEFITS

The impact of benefits on various interest groups in the United States is an important concern. If the benefits of the Landsat Follow-on program were to accrue exclusively or foremost to a few private corporations, then the investment - however worthwhile - should be financed by those few who benefit from such programs. On the other side, if benefits are widespread, across a variety of groups, interests and regions, then programs considered for federal funding have met one important, necessary condition.

In the case of Landsat agricultural crop information, the main beneficiaries will be farmers and consumers. Considerable effort has gone into determining more precisely the exact share by farmers, as against consumers, but to date the results have not been conclusive.

The main, immediate effect of improved crop information will be more stable prices, while in the longer term production will increase at lower overall costs per unit of output. In the economic community there is some disagreement whether stable, nonsubsidized prices benefit farmers or consumers to a greater degree. Our view is that in closed economic systems such price stability as is created by improved information will mainly benefit consumers in the long run, although in the short run farmers are likely to be the main beneficiaries. The economic answers on the share in the overall U.S. benefits depends on many detailed assumptions and estimates, where a small change in parameters can lead to a substantial shift in the share claimed for farmers and consumers - without changing, however, the total estimated benefits accruing to the United States.

Table 3.3 reflects the qualitative judgment that the benefits from distributing crops better will accrue primarily to farmers, if current assumptions in economic theory on the subject are accepted. In a competitive economic system, these benefits will undoubtedly also be shared by consumers over time. The benefits from production effects of improved crop information will go primarily to consumers.

Table 3.3

Long-Term Steady State Distribution of Benefits
Within the United States

Groups	Distribution Effects	Production Effects
Farmers	most	negligible
Traders	negligible	negligible
Consumers	some	most

Small traders and other middlemen in the commodity markets between farmers and consumers cannot afford to collect more reliable worldwide crop information which a few large organizations and corporations can collect on their own. A truly worldwide, timely, public crop information system therefore can be expected to improve, marginally, the position of small farmers and traders relative to large trading and processing interests. Overall, in competitive economic systems the traders and processors will be about equally well off with or without improved crop information. There will exist a diminished need for hedging and speculative risk taking, which again is of some benefit to the economy and to consumers and farmers.

Other than this qualitative assessment, no further, more precise or quantitative statement can be made with assurance.

3.4 DISTRIBUTION, PRODUCTION AND INTEGRATED MODELS

In order to estimate the benefits of improved crop information systems, we have modeled distribution and production aspects of information in agriculture. These models were validated against the real world to the extent possible and used in determining the sensitivity of the benefits to alternative assumptions and capabilities.

The Production Benefits model is essentially a linear recursive econometric model of the world wheat markets, with the major influences being found in the work of Wisecarver (1974), Harberger (1971), Schmitz-Bawden (1974), and Takayama-Judge (1971). The Distribution Benefits model has a different heritage. Here the main influences were Hayami-Peterson (1972), Bradford-Kelejian (1974), and Arrow (1974). In addition to these, reference should be made to the Gustafson paper (1958) which, although not available to ECON during the modeling effort, is remarkably similar in spirit to the Integrated model.

3.4.1 Distribution Benefits Model

The Distribution Benefits model is concerned with measuring the benefits from the improved temporal and spatial distribution of food supply made possible by improved crop forecasts. The measure of benefit is the difference of the value of the crop as distributed with today's information, compared with the value that might be possible with improved information.

The model treats two kinds of distribution: that obtained by shipping commodities from one region to another, and that obtained by storing commodities for consumption in the future.

The role of information then is rather straightforward: International trade will be efficient only if one knows early enough about regional shortages; and similarly, commodities will be stored only if one knows early enough about particular future shortages of food.

The underlying logic of distribution benefits from improved global crop information is this:

1. Improved information from remote sensing leads to more accurate and timely crop forecasts. This improvement is measured by the reduction of the variance of crop forecast errors, month by month.
2. Improved crop forecasts lead to a better time pattern and level of inventory buildups and depletions, since crop forecasts are inputs to inventory holding decisions.
3. Different time patterns of inventory buildup and depletions will reduce the variability of the supply of commodities available for consumption.
4. This more even supply of commodities leads to gains to consumers and producers through price stabilization.
5. The exporters and importers share in the benefits in complex but calculable ways, determined by the workings of the free market.

Thus, improved information working through inventory decisions reduces the variance of food supplies, and thereby generates benefits.

The basic approach is that of modeling the distribution process as a dynamic control process (Andrews, June 1976). An overview of this basic model is given in Figure 3.3. Production of wheat in the United States and in the rest of the

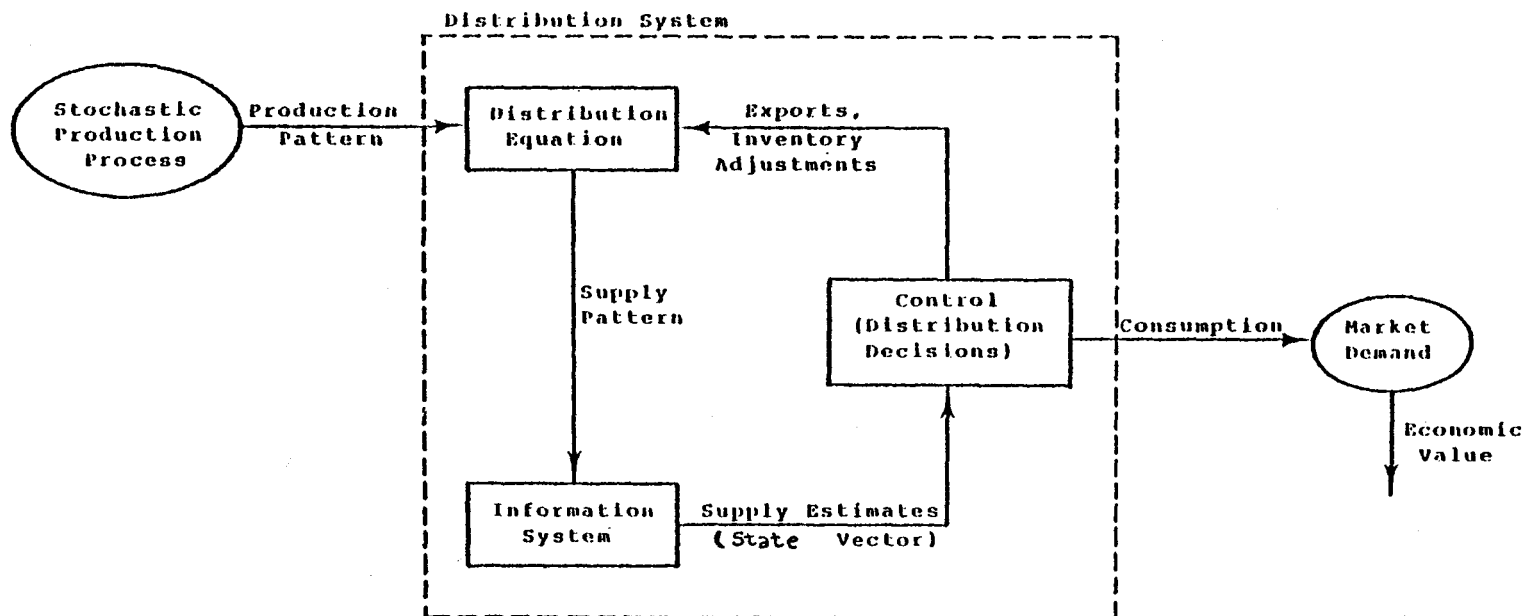


Figure 3.3. Overview of Feedback Control Distribution Model

world is described by a stochastic production process which is considered fixed and exogenous to the control process. This is indicated by the oval block to the upper left. The three interrelated blocks constitute the distribution system which converts the worldwide production pattern into the worldwide consumption pattern. Also fixed and exogenous is the market demand model, which converts a given consumption pattern into economic value. This is shown on the middle right of Figure 3.3.

The distribution process, shown as a rectangular block, is simply the linear relation describing how exports, production and inventory adjustments affect the supply pattern. The system is subject to partial control through export decisions and inventory adjustments. The control is only partial since production has a random component. However, the application of the control is made in the light of estimates of supply provided by an information system. Simultaneously with the decisions on exports and inventory adjustments, the control block produces the consumption pattern as an output of the entire distribution system.

The use of the model outlined above in determining the value of production information is straightforward. One simply observes how the optimum changes in response to selected changes in the information system. In a free market, nonoptimal distribution patterns cannot long survive because they would provide opportunities for arbitrage. In other words, the distribution decisions made by free market agents are such as to maximize the value to the economy.

3.4.2 Production Benefit Model

The underlying logic of production benefits from improved global crop information is as follows:

1. Improved crop forecasts will be more stable.
2. More stable forecasts make possible better planning decisions by farmers, storage decisions by inventory holders, and export-import decisions by traders.
3. Improvements in these decisions lead to price stabilization and an expansion of crop supplies available.
4. The reduced risk in the production and trade of crops, and the increased stability of supply represents benefits to the United States.

All these effects tend to occur simultaneously, as illustrated in Figure 3.4.

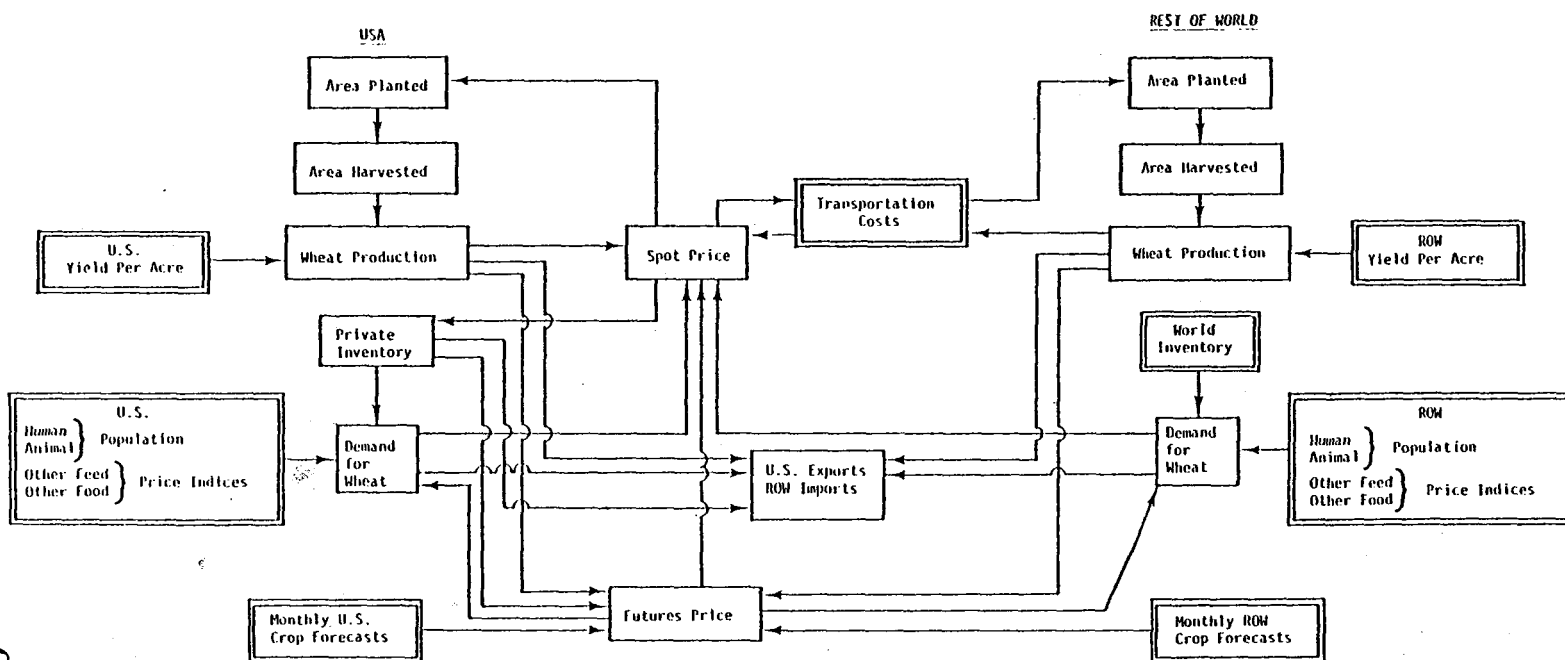
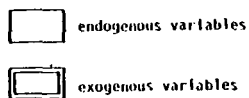


Figure 3.4. Flow chart of World Wheat "Production Benefits" Model

The production model contains four types of equations, which can be thought of as the four building blocks of the model. First, there are demand equations: for human consumption, for animal feed, seed exports and inventories. These equations are present both for the United States and for the Rest of World (ROW). Second, the supply side is represented by equations for planted and harvested acres. Planting decisions are analyzed with respect to price wherever possible. The yield per acre is treated exogenously. Third, there are the market equations detailing spot and future prices in relation to supply forecasts and inventory levels. This block also contains equations representing hedging and speculation on the Chicago futures market, which is taken as the one world market for wheat futures. Fourth, the benefits of improved wheat forecasts are calculated in the final block, which compares prices and quantities under the historical regime of forecasting with prices and quantities under the simulated new regime.

We note that only planting decisions are modeled, as these are by far the most important production decisions. In the United States, planted acreage is used as a data input. In the rest of the world, harvested acreage is used as a stand-in for planted acreage, since in many cases the latter was not available.

Since the price and flow of commodities are conditioned by the availability of other substitutes (e.g., corn for wheat as animal feed), it is necessary to take into account the nonzero cross-elasticities of various crops with respect to the prices of their substitutes and complements. These factors are treated in the model as exogenous and appear in the various demand and supply equations.

The spatial equilibrium - the adjustment of prices, inventories, products and trade patterns - in the model arises from our aggregate treatment of the world as being divided into two regions: the United States and the Rest of World. This necessary simplification reduces "trade" to United States exports and ROW imports.

Owing to the nature of this study, "time" also is an important dimension in the model. It is essential for a number of reasons. First, commodities can be carried from one period to the next depending on the inventory holder's reaction to market anticipations. These anticipations can change from month to month and so can the inventory holder's positions. These changes, of course, influence benefits through price and consumption. Second, the benefits measured in this model, as in reality, depend heavily on the accuracy of market anticipations which, in turn, are a function of crop forecast accuracy. The forecasts play a central role in the model. They represent the best instrument we have for measuring the state of information on the future supply of commodities to the markets. By calibrating the model with historical forecasts and then replacing these

by simulated forecasts which reflect the improvement in crop information resulting from the Landsat system, we have a tool for evaluating the economic effects of crop information in the world commodities market.

The heart of the production benefits model is the supply block, which describes the link of commodity prices to production decisions by farmers. The domestic production in any country is decomposed into harvested acreage A_t times yield Y_t .

The planted acreage of a crop in any period is related to the futures price of that crop, and the previous year's acreage.

Given econometric estimates of U.S. and Rest of World demand and supply characteristics, estimates of the cost of inventory holdings, and average values of commodity futures prices and crop forecasts, the model calculates the downward shift in the cost of supply as a function of forecast accuracies and timeliness.

The production benefits are derived from the effect of changed prices on changing total U.S. production. The changes in production (a net increase) is then related to changes (benefits) in domestic consumption, net storage and exports. These benefits are the result of increased production, lower costs of supplying commodities in combination with the increased consumption made possible by lower prices.

3.4.3 The Combined (Integrated) Benefit Model

In the distribution and production benefit models, two separate lines of study were pursued. One line is empirical, involving the analysis of various time series of agricultural statistics, and using econometric techniques to determine the behavioral relationships between forecast accuracies on the one hand and prices, production, exports and stocks on the other hand. With this approach, conclusions are obtained on the impact of improved information on the operation of the commodity markets, and using the net change in consumer and producer surplus benefits to the United States are estimated (production benefit model).

The second line of study is partly normative. Rather than simply observing how commodity markets have operated under past conditions, one assumes that decisions under any conditions of information are made in accordance with economic objectives. Thus, one builds a mathematical model of decision making to describe the response of production, stocks and exports to information and changes in information. Using standard economic models of demand and supply, calibrated to historical data, one then translates these responses into economic benefits in various market agents in the United States and elsewhere. Distribution

benefits of improved information were studied in this way. The benefits estimated have been based on the assumption that the quantities produced are unchanged under the conditions of improved information.

In the integrated benefit model, the production and distribution benefits of improved information are combined into a single model by extension of the distribution benefits model presented above in 3.4.1 and 3.4.2. The model describes crop production and distribution at a high level of aggregation. The trading units are the United States and the aggregated rest of the world. Trade among the various regions making up the rest of the world is not considered.

The integrated model is an idealized description of the process by which successive annual crops of varying sizes are produced throughout the world and then distributed to consumers at different times and places. Thus, we are modeling the activities of crop production, inventory management and international trade. The various market agents performing these activities can be classed as farmers or producers, speculators, inventory holders, exporters, importers and so on. Our model describes the decision making of these agents and its consequences over an extended time period. The system described by this model is very similar to the distribution model, except that production decisions are now also included.

A basic feature of the model is that it is dynamic; that is, that it explicitly treats changes of its fundamental variables through time. In fact, it has been found necessary to include year to year coupling by modeling an extended time period of many years. This builds a formal structure that leads to practical calculations for any time horizon. This has been accomplished in the present work, which incorporates an infinite time horizon.

A fundamental simplifying principle used in this model is that all decisions are made through the operation of a free market, so that production, exports and inventories take on levels permitting no further investments or transactions producing a positive mean present value. This assumption is made for the current as well as the improved crop information systems. The exclusion of such arbitrage opportunities amounts to the exclusion of opportunities for increasing the sum of mean economic value to all market agents. Thus, the free market assumption implies that the aggregate decisions are optimal in the sense of maximizing this sum of mean economic value. Because these aggregate production, trade and inventory holding decisions are optimal, we need not model the decision making of the individual market agents such as farmers and exporters. Instead, we model the system as if each consuming and producing unit were con-

trolled by one rational individual, consciously seeking the maximization of total mean economic value.*

Though we do not model the decision making of individual market agents, we do model the economic consequences of these decisions to the various classes of market agents. For instance, we determine such quantities as total U.S. exports, total costs incurred by producers, net revenues to traders, etc.

Our model takes the form of a dynamic control process. The system of production distribution, information use and consumption is described by time-dependent state variables, control or decision variables and a state transformation. An overview of this model is given in Figure 3.5.

The block at the bottom of this diagram describes the production and distribution system itself, which is partially controlled by the decision variables: planting, exports and consumption. The state of this system at any time is the supply (stocks and growing crop), which is represented as the output arrow left of the block. The control of the system is only partial, since yield is uncertain. Consequently, the state of the system is uncertain; it (supply) is not automatically known. The information system, diagrammed at the left of the figure, produces supply estimates. These supply estimates at any given time form the state variables of the model. Decisions are made in the light of the supply estimates coming from the information system, and the economic data evident in the commodities markets. In particular, the value produced by making one decision or another can be determined from the elasticities of production, demand and transportation, and the interest rate (for determining cost of storage). This economic value calculation is both a part of the decision or control process, and the source of the basic output of the model, shown as the output arrow of the rightmost block in Figure 3.5. The benefits resulting from this combined (integrated) evaluation are the basis for the overall evaluation of agriculture crop benefits.

3.5 WORLD CROP INFORMATION TODAY AND WITH LANDSAT

While the measurement accuracies of a future global Landsat Follow-on system can be analyzed technically, one of the great difficulties today is to determine the current state of worldwide crop information. While most people would think that nothing is simpler than to estimate harvests, the fact is that today, no such

*This is a generally valid insight for competitive market economies, equivalent to complete information in centrally planned economies. For an overview on this issue see Kenneth Arrow, "Limited Knowledge and Economic Analysis," *American Economic Review*, Volume 64, No. 1, March 1974.

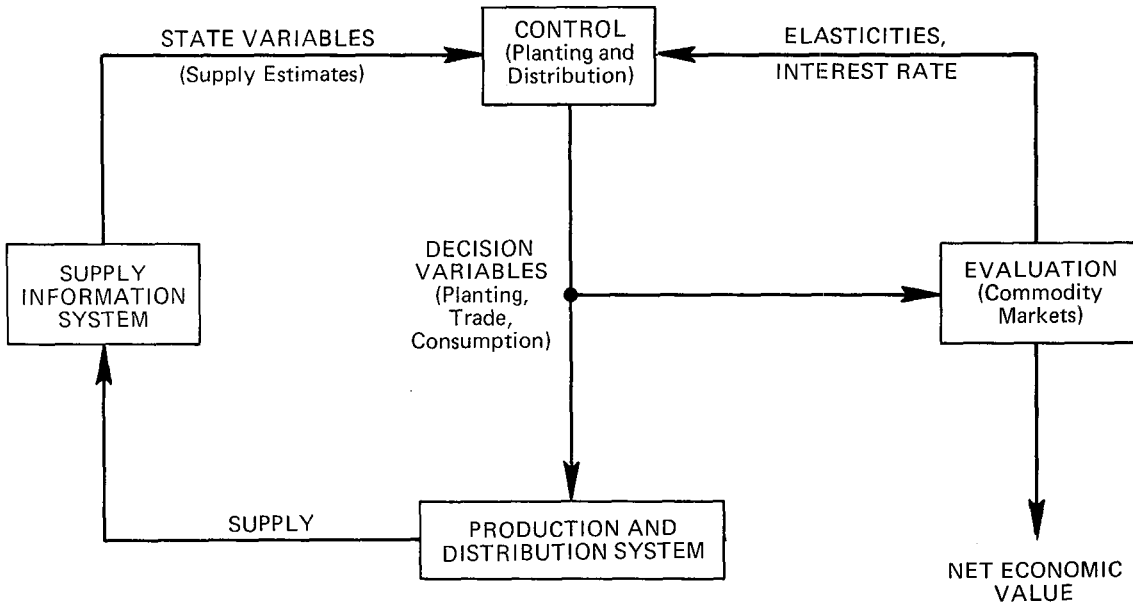


Figure 3.5. Overview of Combined (Integrated) Benefits Model Decision Process

revised final estimate exists for many countries. Furthermore, even where final estimates are available, they often vary widely from the forecasts made during the growing season.

In the worst cases, one finds that original planning numbers of some countries - say as part of a five-year plan - become precisely that country's crop forecast, which in turn becomes precisely the reported wheat harvest, with or without "overfulfillment" built in. It is difficult - on the face of such evidence - to get a true assessment of the accuracy of crop forecasts and measurements.

In the published forecasts of harvest by the world's largest grain producer, the USSR, there are apparently enormous errors and fluctuations. Witness the large surprise shortfalls in 1972 and again in 1975. In cases like this, the United States can benefit from more objective crop reporting, whatever the accuracy of the forecasts that may be employed within the USSR.

We note, however, that the quality of data for some areas of the world - notably the United States and Canada - is quite good (Gunnelson, Dobson and Pamperin 1972 and Warren 1976).

Estimates of Landsat's potential capability require understanding how remote sensing inputs fit into the total forecasting system.

The crop production forecasts are the result of a process of data collection, evaluation and integration which is illustrated in Figure 3.6. The errors in the final forecast are a composite of errors of sampling, measurement and inference.

In order to determine the numerical value of specific improvements in world-wide crop production information, we need numerical descriptions of both the current estimating and forecasting capability and the specific improved capability under analysis. Our numerical description of the current capability is based on a statistical analysis of published estimates and forecasts over the past 14 years. Our numerical description of the improved capability is based on two approaches mentioned in Section 3.1. The first approach which was used for the baseline benefit estimates is described in Section 3.5.2, while the Sigma Squared approach and results are discussed in Section 3.5.3.

3.5.1 Current Crop Information System

To construct a statistical description of the performance of an existing crop production information system, we begin with a table of published forecasts. In Tables 3.4 and 3.5 are given 14 years of monthly wheat production estimates for the United States and for the aggregated rest of the world respectively. The sources of these data are discussed in the ECON, Inc. reports, e.g., Andrews (November 1976).

As in the case of improved information, only public information is included in the assessment of the current information system. The best available sources of such information were used. Foremost among these are the publications by the Foreign Agriculture Service of the USDA and the Grain Bulletin of the Commonwealth Secretariat in London, U.K.

Tables such as 3.4 and 3.5 provide a matrix of estimates which we can denote $F = (F_{ij})$. In our applications, F is a 13 x 6 matrix, but in the following discussion, we will leave the shape general, so F is assumed to have m rows and n columns. As is clear from Tables 3.4 and 3.5, the wheat production system has been growing, so that the numbers in the bottom rows of F are considerably larger than in the top of F . Since we want to use all of F in the statistical analysis, but apply the results to a future time (when Landsat is operational), some kind of normalization is required. Most likely, the wheat production system will continue to grow in the future, but it is difficult to predict whether the growth rate will be as great as in the recent past. We take a conservative position in this study, by assuming the system will operate in a steady state, at a

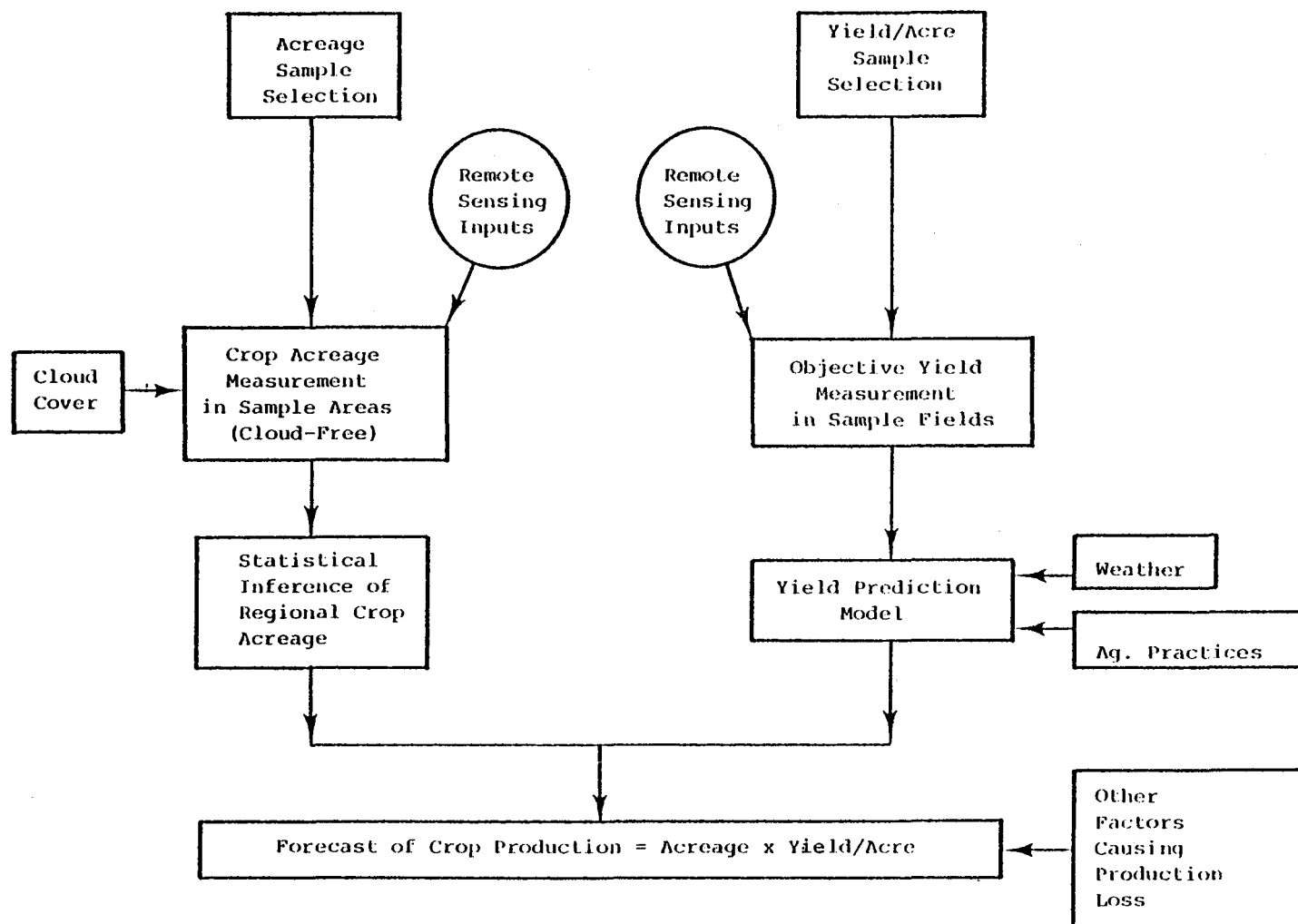


Figure 3.6. Illustrative Flowchart for Crop Forecasts

Table 3.4

U.S. All Wheat Production Estimates, June, August,
October, December and Final, Millions of Bushels

Year	June 1	August 1	October 1	December 1	Final
1961	1343	1204	1211	1235	1232
1962	1058	1063	1095	1092	1092
1963	1084	1151	1133	1137	1147
1964	1213	1285	1286	1290	1283
1965	1283	1376	1354	1327	1316
1966	1235	1286	1296	1311	1305
1967	1550	1511	1554	1524	1508
1968	-	1606	1598	1570	1557
1969	-	1459	1456	1459	1443
1970	-	1357	1360	1378	1352
1971	-	1601	1628	1640	1618
1972	-	1543	1559	1545	1545
1973	-	1717	1727	1711	1705
1974	-	1840	1781	1793	1796

Table 3.5

Aggregate Rest of the World Wheat Production Estimates, June, August,
October, December, February and Final, Millions of Metric Tons

Year	June	August	October	December	February	Final
1961	178.75	178.75	178.75	178.75	177.32	143.30
1962	183.76	185.04	172.74	172.74	172.74	153.15
1963	182.90	188.47	202.35	202.06	204.06	184.18
1964	192.19	192.62	201.63	200.63	205.92	165.02
1965	189.05	190.91	193.77	193.77	201.20	194.48
1966	195.91	201.20	208.49	207.21	204.78	177.03
1967	199.34	199.77	208.35	208.64	209.78	231.23
1968	210.64	215.93	215.07	231.66	228.09	201.77
1969	218.65	218.65	227.37	231.37	230.80	237.67
1970	242.81	242.81	243.39	245.96	246.25	215.22
1971	235.52	235.52	227.66	243.39	240.24	224.37
1972	250.82	250.82	260.26	259.12	257.54	245.67
1973	253.68	254.11	264.69	265.12	270.27	255.68

scale corresponding to the present time. Thus, we begin by normalizing the tables, dividing each estimate by the final estimate for its crop year. Algebraically, we replace F with

$$N = (N_{ij}),$$

where

$$N_{ij} = \frac{F_{ij}}{F_{im}}, \quad i = 1, \dots, m, \quad j = 1, \dots, n.$$

Tables 3.6 and 3.7 give these normalized estimates. We will determine mean squared errors in this dimensionless form, and then multiply them by the squares of the current typical United States and rest of the world annual wheat production figures, which are approximately 50 million metric tons and 300 million metric tons respectively.

Assuming the final estimate to be correct, the errors of the estimates in the preceding months are derived from Tables 3.6 and 3.7. In Table 3.8 the mean squared errors by month are tabulated based on the fourteen year data of the previous tables. These errors are listed both as a fraction of the assumed nominal production and in millions of metric tons squared. The corresponding root-mean-squared errors are also presented for convenience.

The assumption that the final estimate is correct for modeling the current errors is optimistic. Consequently, it is assumed that some residual error is present in these final estimates. In the United States the residual error might be quite small*, however, in the Rest of World, the residual error is probably substantial. Our assumption of 5 percent residual error for Rest of World and zero for the United States is believed to be conservative.

The error in the published United States forecasts decrease through the crop year, while those in the Rest of World remain essentially constant. According to Table 3.8, the errors in the Rest of World actually increase slightly over time through the crop year. Although this increase is a property of the published data, it cannot be a property of the information used for rational judgments in the commodity markets. If the estimates published in June are known to be

*In the United States the Bureau of the Census makes every five years an *independent* estimate of United States crops. These estimates differ from USDA final estimates (one year after preliminary final estimates) often by several percentage points for most crops. Definitions, samples and measures used differ in the two cases, as one would expect. This goes to show that even for the United States, it is difficult to determine precisely the performance of the current crop information system. In the interest of a conservative assessment, USDA final estimates are assumed in this study to be error free.

Table 3.6

Normalized U.S. Wheat Production Estimates

Year	June	August	October	December	Final
1961	1.090	0.977	0.983	1.002	1
1962	0.069	0.973	1.003	1	1
1963	0.945	1.003	0.988	0.991	1
1964	0.945	1.002	1.002	1.005	1
1965	0.975	1.046	1.029	1.008	1
1966	0.946	0.985	0.993	1.005	1
1967	1.028	1.002	1.030	1.011	1
1968	-	1.031	1.026	1.008	1
1969	-	1.011	1.009	1.011	1
1970	-	1.004	1.006	1.020	1
1971	-	0.989	1.006	1.014	1
1972	-	0.999	1.009	1	1
1973	-	1.007	1.013	1.003	1
1974	-	1.024	0.992	0.998	1

Table 3.7

Normalized Rest of the World Wheat Production Estimates

Year	June	August	October	December	February	Final
1961	1.166	1.166	1.166	1.166	1.157	1
1962	1.120	1.208	1.128	1.128	1.128	1
1963	0.993	1.023	1.098	1.097	1.108	1
1964	1.165	1.167	1.222	1.216	1.248	1
1965	0.972	0.982	0.996	0.996	1.035	1
1966	1.107	1.137	1.178	1.170	1.157	1
1967	0.862	0.864	0.901	0.902	0.907	1
1968	1.044	1.070	1.066	1.148	1.130	1
1969	0.920	0.920	0.957	0.973	0.971	1
1970	1.128	1.128	1.130	1.143	1.144	1
1971	1.050	1.050	1.015	1.085	1.048	1
1972	1.021	1.021	1.060	1.055	1.048	1
1973	0.992	0.994	1.035	1.037	1.057	1
1974	0.920	0.920	0.911	0.975	0.976	1

Table 3.8

Error Statistics on Published Wheat Production Estimates
MMT = Million Metric Ton

	United States		Rest of World	
	Fractional	(MMT)	Fractional	(MMT)
Mean Squared Errors				
Jun	0.001766	6.92	0.01143	1028
Aug	0.0004	0.97	0.01243	1119
Oct	0.0002	0.616	0.0129	1159
Dec	0.00008	0.192	0.0138	1245
Feb	-	-	0.0142	1274
Root Mean Squared Errors				
Jun	0.0526	2.63	0.1069	32.07
Aug	0.0197	0.985	0.1115	33.45
Oct	0.0157	0.785	0.1135	34.05
Dec	0.0088	0.44	0.1176	35.28
Feb	-	-	0.1190	35.7
Assumed U.S. wheat production is 50 MMT and ROW wheat production is 300 MMT. Errors are in reference to final estimates.				

superior to those published later (on the average), the later ones will be ignored. Thus, we take the error of the June estimate (10.69 percent) as holding throughout the crop year, until the beginning of the final period (April), at which time we assume the market acts as if the true production is known. This assumption favors the stated performance of the current crop information.

For our benefits analysis, the useful form of the description of information system performance is the sequence, σ_j^2 , of month-to-month changes in variance V_j of the annual production estimate. We form the successive differences

$$\sigma_j^2 = V_{j-1} - V_j$$

where V_j is approximated by the mean squared error in the monthly estimates given in Table 3.8. Since there is no pre-June forecast σ_j^2 , corresponding to June, is the variance of the June forecasts of Tables 3.6 and 3.7 and not of its error with reference to the final estimate. This variance of the June forecast

is 6.39 (million metric tons)² in the United States and 895 (million metric tons)² for Rest of World.

Table 3.9 gives the mean square errors (V_j) and the difference variances (σ_j^2) for the United States and Rest of World. The sum of the six σ_j^2 s plus the residual error variance represents the a priori variance of the annual wheat production, while the sum

$$\sum_{j>J} \sigma_j^2$$

represents the remaining variance after obtaining information at time J. Thus, the a priori variance for the Rest of World used in the baseline system is 2,148 (million metric tons)², and 13.31 (million metric tons)² for the United States.

Table 3.9

Forecast Difference Variances for Current Information System
(In Millions of Metric Tons Squared)

Month	United States		Rest of the World	
	Mean Squared Error V		Mean Squared Error V	
Jun	6.920*	6.390	1028*	895**
Aug	0.970*	5.950	1028*	0
Oct	0.616*	0.354	1028*	0
Dec	0.192*	0.424	1028*	0
Feb	0.192*	0	1028*	0
Apr	0*	0.192*	0*	1028*
*Residual error variance to be added to this figure.				
**Variance of the June forecasts not referenced to the final estimate.				

3.5.2 Improved Crop Information System with LACIE Goal

The LACIE 90/90 goal can be interpreted as the achievement of estimates of wheat production at harvest with relative standard deviation error of 6.1 percent. This LACIE goal is by country so that if all the wheat harvests occurred at one instant around the globe the Rest of World at harvest accuracy would average out to a much lower standard deviation than 6.1 percent; assuming the estimation error to be somewhat independent in different regions of the world. However, harvests occur at different times in the various regions of the world, so that application of the LACIE goal to the Rest of World forecast estimates requires combining the errors of each region by its time phase and weighted by the size of its production. Various models for characterizing the Rest of World forecast errors were studied, and it was found that a simple two segment model of the variance was adequate. Since the system can be expected to produce steady improvements in accuracy through the entire worldwide growing and harvest period, a linear decline model for the progression of mean squared error over time was used. Improvements begin for the rest of the world with the June 1 forecast. The next estimate, August 1, has standard error 6.1 percent, and improvements continue period by period until the true production is discovered April 1, the beginning of the final period (e.g., through inventory accumulation or depletion). This baseline model leads to forecast difference variances (σ_j^2) as given in Table 3.10. Also included in Table 3.10 is the current system performance. These variances are used in the benefit calculations and in the sensitivity calculations of Figure 3.2. Note that in both the distribution and integrated models the information is characterized over a two-year period. The corresponding forecast accuracy from Sigma Squared is also tabulated in Table 3.10 and discussed below.

3.5.3 Sigma Squared Study

The agriculture benefits depend on the improvement in production forecast information in each country over the current forecast information, month-by-month throughout the growing season. As mentioned earlier, the statistical characterization of the current and Landsat based information necessary to estimate the benefits is the standard deviation (σ) of the production forecast error, hence the name of the study. In previous benefit estimates this production forecast error by month, by crop, and by country had to be assumed. That assumption was that a Landsat system would give a production forecast accuracy of 6.1 percent (relative standard deviation) at harvest, with the additional assumption that the error statistics are normal. To derive the economic benefits the production accuracy at harvest had to be extended backwards in time all the way to planting as discussed in the previous section. Thus, the object of the Sigma Squared study was to characterize the variation of the production forecast

Table 3.10

Two Year Model of Variance Behavior of U.S. and ROW

Bimonthly Change in Variance σ_j^2 (Millions of Metric Tons) ²				
Period	Current System		90/90 Baseline System	Sigma Squared (TM)
	U.S.	ROW	ROW	
Prior - June	0	0	0	0
Jun - Aug	0	0	0	0
Aug - Oct	0	0	0	607
Oct - Dec	0	0	0	237
Dec - Feb	0	0	0	19
Feb - Apr	0	0	0	210
Apr - Jun	6.39	895	1743	900
Jun - Aug	5.95	0	81	111
Aug - Oct	0.354	0	81	28
Oct - Dec	0.424	0	81	2
Dec - Feb	0	0	81	0
Feb - Final	0.192	1253	81	34
Total Variance	13.31	2148	2148	2148

accuracy of the Landsat Follow-on with the Thematic Mapper by crop, by country, by month. This section summarizes this study which was initiated in July 1976. The final report on this study should be available in March 1977, however, the study has already supplied us its main output, the wheat and corn forecast accuracies, in the major countries. Table 3.10 is aggregated from the result of this preliminary output.

The major contribution of Sigma Squared was in the simulation of the area classification error as shown in Figure 3.7. Thus, as seen in Figure 3.7 the simulation is based on signature statistics which are obtained from LACIE and simulated TM data from ERIM (1976) studies. The LACIE classification procedure is modeled as shown, and the resulting simulation is validated by the LACIE performance results. To extend the data to foreign countries field size distribution histograms were necessary as shown in the figure. The signature data based on crop calendar is the basic input to define the area forecast accuracy by month.

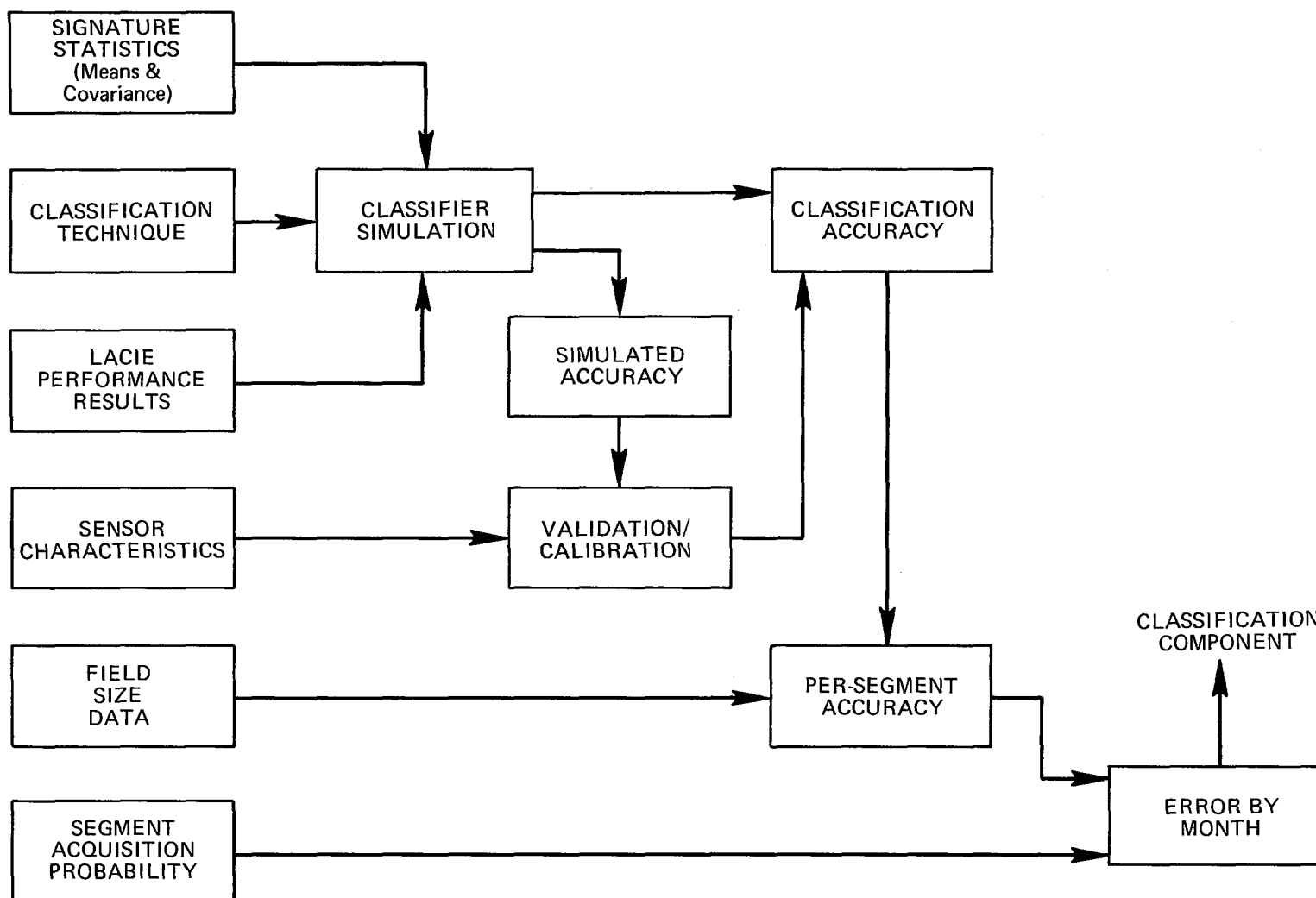


Figure 3.7. Sigma Squared Classification Error Component Simulation

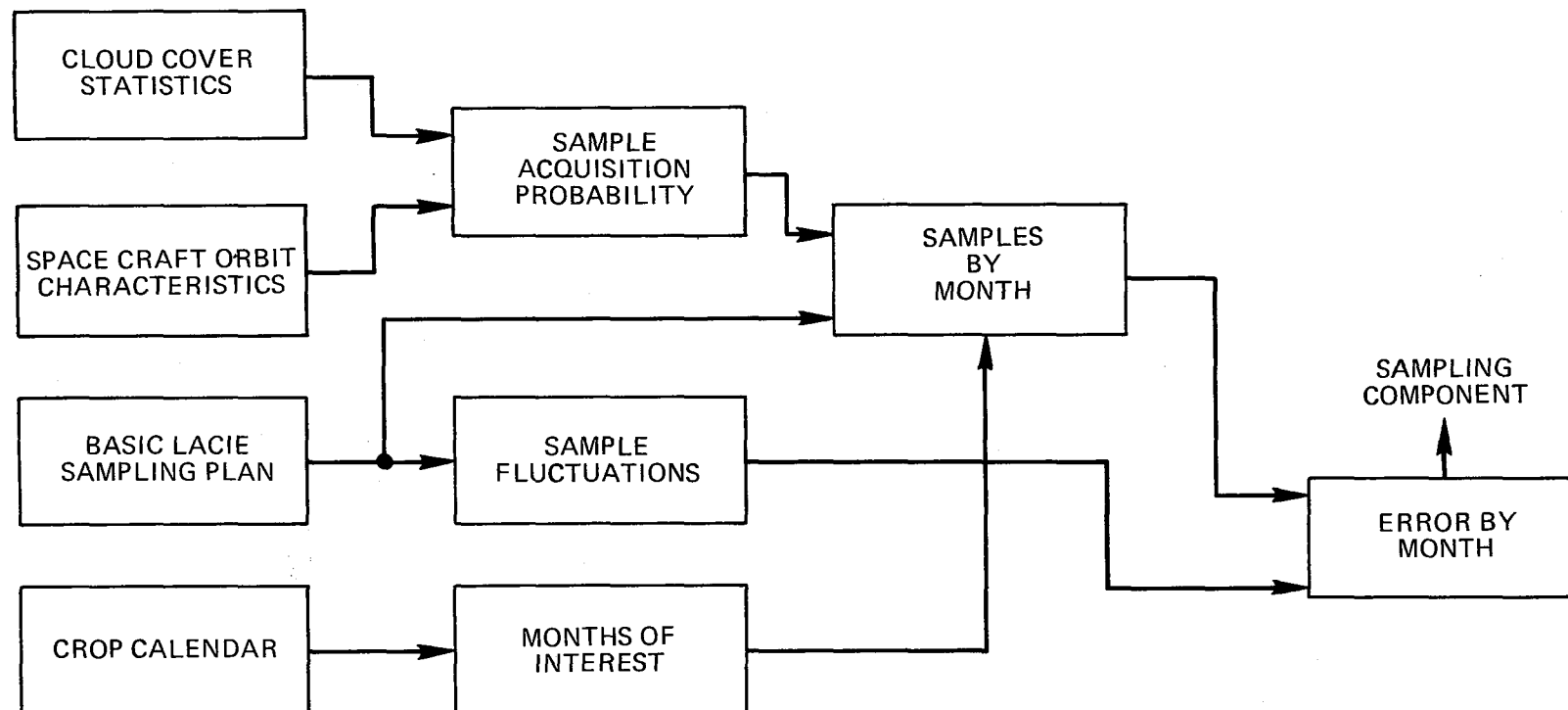


Figure 3.8. Sigma Squared Sampling Error Component Simulation

Figure 3.8 similarly shows the Sigma Squared simulation for determining the area sampling error. An important input here is the data on global cloud cover statistics that affect the sampling error.

The total production forecast error is the sum of the classification error, the sampling error, and the yield error. Yield error was conservatively estimated based on FAS/USDA ten year trend data. The final result as observed earlier is that the Landsat Follow-on system can be expected to forecast production of wheat and corn in economically important countries to better than 90 percent accuracy, 90 percent of the time, at harvest.

4. PETROLEUM AND MINERAL EXPLORATION

4.1 INTRODUCTION

Present Landsat multi-spectral scanner imagery is already a tool for petroleum and mineral exploration companies. The added spectral bands and increased spatial and radiometric resolution of the Thematic Mapper promise to make it far more effective. Testimony of industry experts indicates a tremendous potential. However, due to the proprietary nature of exploration, and the long lead time from exploration to public confirmation of discovery, it is difficult to document all the benefit mechanisms. Thus, in contrast to Agriculture where a major benefit could be quantified, in the petroleum and mineral area only the relatively, smaller benefit of this application has been quantified.

Benefits from Landsat to petroleum and mineral exploration may be divided into two categories:

- Cost savings are achieved in the exploration for both petroleum and minerals, because Landsat is useful in screening prospects, laying out geophysical surveys more efficiently, and achieving exploration goals at lower cost. Total savings to United States companies are estimated to be in the range of \$64 million to \$260 million annually, based only on efficiencies demonstrated from early Landsat experience without the Thematic Mapper. With the Thematic Mapper larger benefits are anticipated, owing to the greater efficiency of screening prospects that should result from additional spectral bands and greater resolution.
- Increased values are obtained from earlier recognition of good prospects. A prospect has a market value that takes into account remaining exploration, development and recovery costs; the probable yield of the ore bed or petroleum field; and the perceived risks at each stage. The benefit derives from capturing this market value at an earlier date. Although there is good evidence that Landsat can speed up prospect recognition, some further study is required to permit estimating Landsat's quantitative effect, and to assess the market values of the resulting prospects.

A case can also be made that Landsat should speed the discovery of petroleum in countries not currently holding proven reserves. This should be of major benefit to oil importing nations, as extra producers will tend to reduce the price level at which OPEC can effectively control production levels. The magnitude of this effect is very difficult to estimate, although it is potentially of major significance.

A few final comments are merited. First, cost savings resulting from improved efficiencies tend to be reinvested in further exploratory work, since the "cost per find" is reduced while the market value is not. The "cost-saving" measure, therefore, is a minimum valuation procedure. Second, many Landsat images of the same area may be used in screening, since subtle differences in lighting, soil moisture and vegetative color provide valuable clues. Several years of Thematic Mapper imagery will be needed to provide a reasonably complete set of data for this application; a single, complete set of images would have more limited usefulness. Furthermore, an iterative process of cross-checking between imagery and field investigations is required, so that the benefits are likely to be realized over a period of many years.

4.2 COST-SAVINGS EFFECTS

In petroleum and minerals exploration it is rare for any one tool to provide definite evidence of a new reserve. Instead, the process is one of identifying and further screening of prospects before the larger investments in test drilling of the best prospects is decided. Figure 4.1 illustrates this exploration and development process.

The evidence that Landsat can provide is of fracture patterns suggestive of mineralization, domal outlines and definitions of other structures suggesting locations in which petroleum or minerals may be concentrated, and color differences in rock or vegetation which may be indicative of minerals or hydrocarbons. In some cases other techniques will have suggested prospects that Landsat data

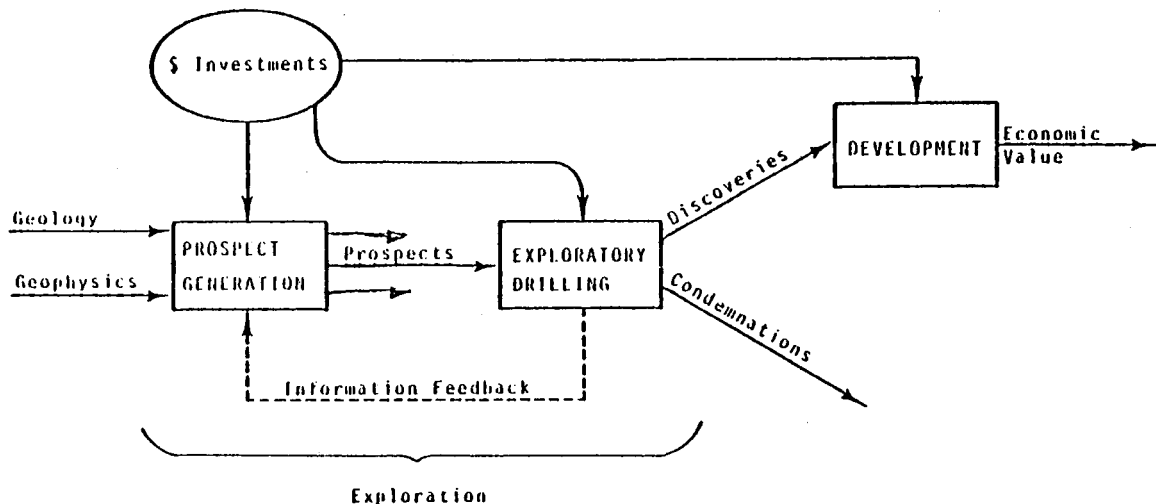


Figure 4.1. The Exploration and Development Process

may be used to suggest prospects to be evaluated by other techniques. The two approaches are really intertwined as shown by the feedback in Figure 4.1. We may regard the former as augmenting the efficiency of exploration geology and geophysics, and the latter as creating prospects with a certain market value. This market value would not be created as soon, if at all, in the absence of Landsat. The impact of Landsat data on the cost of exploration is estimated based on: a National Academy of Sciences study; the results of a questionnaire that was presented to industry members; and on personal contacts with industry representatives.

In the study done by the National Academy of Sciences in 1969, the U.S. Geological Survey (USGS) reported expecting a 7 percent cost reduction using remotely sensed data in their geological and geophysical exploration operations (G&G). We define G&G to include mapping reconnaissance, regional and local geology analysis, surface rock and chemistry sampling and aerial and subsurface geophysical studies. The estimates for G&G cost savings to mineral companies resulting from Landsat were based on a questionnaire survey. The estimates ranged from 12 percent to more than 50 percent. Personal conversations with knowledgeable people in the petroleum industry put the range at 7 percent to 10 percent. However, the definition of G&G activities varies with companies, therefore, we have assumed the 7 percent figure as a conservative cost savings factor. The specific sources for these estimates are listed in Table 4.1.

Next we need to determine the size of the G&G "market." Based on the sources shown in Table 4.1, we estimate that 20 percent to 35 percent of all exploration costs are spent for G&G activities. Several sources were consulted to obtain a projection of the average annual expenditures by U.S. companies for oil and mineral exploration over the period 1980-1995. These put the levels of exploration in the neighborhood of \$1 billion to \$3 billion for minerals and \$5.5 billion for petroleum as shown in Table 4.1.

The cost savings computation is now straightforward and is shown in Table 4.1 as an annual savings in petroleum exploration costs of \$77 million to \$190 million and in mineral exploration of \$14 million to \$70 million. Companies will probably reinvest these savings in their exploration program, so benefits from Landsat will be more exploration rather than more profit.

A different estimate of global G&G activities based on 1975 is given in Table 4.2. This estimate was prepared separately in an independent assessment of cost-saving benefits for the Landsat User's Perspective Document. In Table 4.2 the total G&G of \$1,340 million is reduced by \$420 million which is mainly marine geophysical surveys for petroleum. The final estimate of \$64.4 million annual benefits is obtained using the 7 percent figure given by USGS in the

Table 4.1

Benefits Based on Percentage of Exploration Costs

	FY 76 Dollars	Sources
Exploration Cost		
Mineral	1B - 3B	Battelle Survey
Oil	5.5B	Texas Gulf Industry Report
		Trollinger, Geological Associates
G&G Cost		
Mineral	200M - 350M	20-35 percent of Exp.
Oil	1.1B - 1.9B	33 percent N. Short, GSFC
		25-35 percent Trollinger, Geological Associates
Benefit & Percent of G&G		
Mineral	(7%) 14 - 70M	7 percent USGS/National Academy of Sciences
Oil	(7%) 77 - 190M	12-15 percent Sharon; National Lead
		10 percent N. Short, GSFC
		7-10 percent Trollinger, G.A.
		9 percent N. Short, GSFC
		30 percent Eason Oil Case Study
Total	91 - 260M	(1.4-2.5 percent of exploration cost)

4-4

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Table 4.2

Petroleum and Mineral Cost Savings in Landsat User's Perspective Document

	1975 Global Costs	Sources
Geological Techniques		
Petroleum & Mineral	\$ 100M	The Oil and Gas Journal May 1976, p. 36
Geophysical Techniques		
Petroleum	\$1,190M	Geophysics, Vol. 41
Minerals	\$ 51M	No. 4, 1976, p. 780
Total G&G	\$1,340M	
Less Marine Geophysics	\$ 420M	Geophysics, Vol. 41
On-Shore G&G	\$ 920M	No. 4, 1976, p. 780
Benefit at 7% of On-Shore G&G	\$ 64.4M	1969 National Academy Study

National Academy of Sciences study. Both benefit estimates are presented here since they are based on independent assessments of the limited data on global G&G costs. Combining the two results gives the range of these benefits to be between \$64 million to \$260 million annually.

4.3 INCREASED VALUE OF PROSPECTS

There is substantial evidence that Landsat can enrich the numbers of petroleum and mineral prospects to be screened, as well as providing greater efficiencies in screening the prospects generated from other evidence. These prospects have some "market value," and hence are properly regarded as benefits. If the prospect is one that would have been discovered later, by other means, the benefit lies in the earlier capture of the market value.

The prospects generated by Landsat are of several major kinds, as reported by Dr. N. Short (1976) of GSFC.

- Fracture Patterns. Abdel-Gawad, conducting a pilot study in east-central Nevada, has shown that known mines tend to lie at or near fracture intersections, and that other fracture intersections have unusually great evidence of mineralization.
- Color Anomalies. These may be indicative of alteration by significant trace minerals, escaping hydrocarbons, or other significant geochemical events. Sar Cheshnich in Iran, Goetz and Brockman in Bolivia, and Schmidt in Pakistan have demonstrated that band-ratio anomalies can be used to find alteration zones, many of which were shown on subsequent ground investigation to be good mineral prospects.
- Structural Anomalies. These can be revealed by preferential stream and lake alignment, as investigated by Pickering in Georgia and several investigators in Alaska. Some of these are under active test for petroleum and natural gas at this time, although no conclusive results are yet known.
- Botanical Anomalies. These sometimes indicate trace elements in the soil, and can be detected with enhanced, and usually repetitive, Landsat imagery. A major find of zinc resulted from observation of the tonal differences in vegetation caused by zinc and cadmium in the surface soil. Similar patterns have revealed four additional commercial deposits outside the original zone of exploration.

The prospects generated by Landsat require checking out by other methods including surface investigation, geophysical techniques and test drilling before a "find" can be declared or a prospect rejected. One cannot, therefore, regard Landsat's value in this application as either the full value of reported "finds" or limited to only the "finds" that have been verified.

Prospects in themselves have a definite economic value, however. In the oil industry, for example, many companies and individuals capitalize on this value directly by trading or selling their ideas, rather than investing in exploratory drilling and later development. Generally, both buyer and seller try to evaluate the worth of a prospect by estimating the present net value of the future profits. This can be done with some precision when the prospect has been discovered by more or less standard techniques, and lies in a fairly well explored area. It is much more difficult to evaluate the worth of a Landsat discovered prospect. First, there is secrecy, because companies regard data on prospect quality and market value as a valuable in itself. Second, Landsat is so new that too few Landsat generated prospects have been pursued to provide a reasonable statistical sample.

The best method of arriving at realistic estimates of prospect values is to model a typical evaluation process, and attempt to determine the downstream probability distributions. This requires statistical evaluation of the investigations cited above, enhanced by informed opinions. Such modelling should consider the progressive depletion of ore-bodies or petroleum beds in various areas of the globe along with the costs of following up the prospects. Figure 4.2 provides an illustration of how prospect quality declines over time. Only a fixed number of of prospects are available to be found and it is the nature of the economic process that the best prospects will tend to be found first. What better information, such as that from Landsat, can do is to accelerate the process, so that some of the good prospects that would otherwise be available years later might be added to the prospect inventory now. Work of this kind is now in progress, but results are not yet available. At this time, we do not attribute specific values to the Landsat generated prospects, or the economic worth of obtaining these prospects sooner than would be the case without Landsat. Nevertheless, given the current high expenditures of oil and mineral companies aimed at finding prospects, the values could be very large.

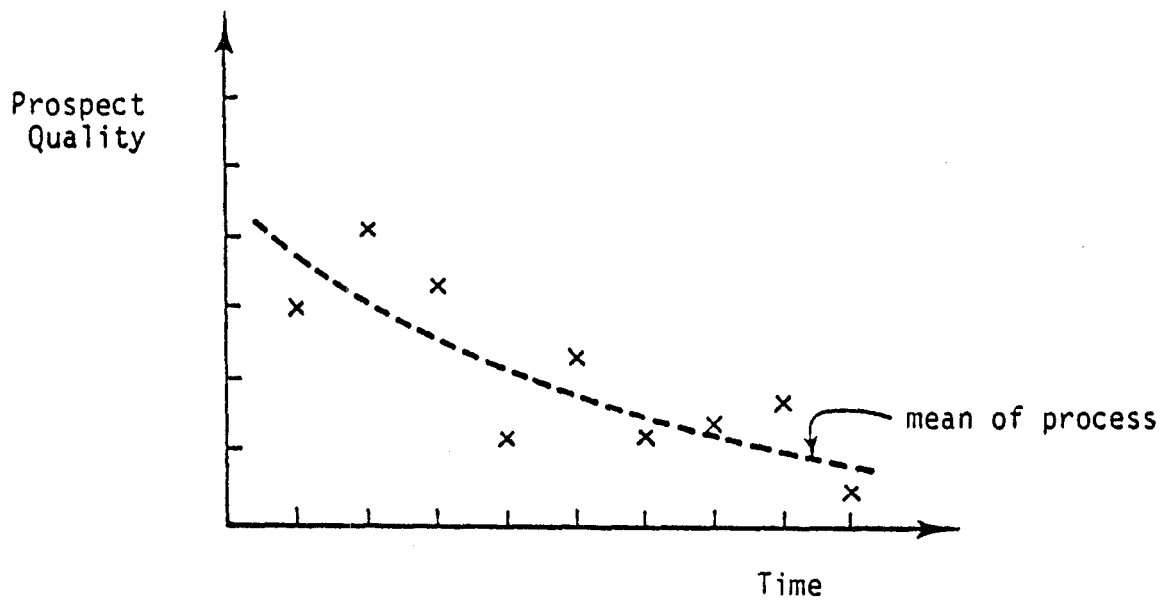


Figure 4.2 Hypothetical Illustration of Random Decline of Prospect Quality Over Time

5. HYDROLOGIC LAND USE

5.1 INTRODUCTION AND SUMMARY

The amount of money spent on water resource systems planning and management is very large. The total federal expenditure for water resource development programs in FY 77 is estimated to be \$2.9 billion (Office of Management and Budget, 1976b). In 1971, the expenditures of local governments on urban water resources problems were estimated to be \$12 billion per year (Office of Water Resources Research, 1971). In metropolitan areas these expenditures constitute 20 percent of the total public expenditures (Koelzer, 1972).

Many of the planning and preliminary design activities on the part of federal, state, and local agencies require land use or surface cover maps. These show the present varied activities occurring within watersheds and provide input data for watershed models which produce estimates of snow run-off volumes, minimum and peak flows, and the assurable flow and minimum flow. Storm runoff volumes and peak flow rates are needed to plan municipal water systems, storm sewers, the size of reservoirs and dams, and flood control structures. Although it is often assumed that most agencies have access to current landuse maps, this is often not the case. In addition, even when maps are available they may not provide the type of information needed for watershed runoff prediction models or engineering design studies. The Landsat satellites can provide maps and numerical data that are timely and accurate, particularly for watersheds larger than 10 - 20 kilometers. In addition the processing of Landsat data can be done in a fraction of the time required by conventional systems.

The remainder of this chapter will document the estimated net savings in the \$15 billion spent annually for water resource systems activities. The end result is that the annual minimum of \$33 to \$35 million of data preparation expenses could be impacted and a net savings of approximately \$22 to \$23 million per year achieved.

The benefits of using Landsat to provide planning inputs arise not only from savings in imagery costs, but also from the ability to automate tasks that otherwise would be performed by hand. These tasks include developing classification systems, measuring areas with a planimeter, and coding information into a form suitable for input into watershed models or other computer programs. Since Landsat data has uniform scale and spectral characteristics, automated systems for data analysis and interpretation can readily be employed. The greatest cost savings are anticipated in applications lending themselves to such automation. Automation can also speed the planning of projects and permit them to be completed much sooner. If funds saved in planning were reinvested in the same programs, as often will be the case, a compounding of benefits could be expected.

It is important to note that water resource planning is an activity that will very likely increase during coming years due to legislation such as the Federal Water Pollution Control Act of 1972. Not only does continuing economic development pose new and different needs for water sources, water treatment, and flood control, but the changes in landuse alter the runoff and pollution parameters needed in the planning models.

Substantial changes in landuse and surface cover are occurring in the United States which require an ability to monitor and translate them into information in order to plan and design water resource systems. Many sources document the scope of the coverage required. The Commission on Population Growth and the American Future (1972), Statistical Abstract of the United States, U.S. Bureau of the Census (1972), Resources and the American Future by Landsberg, et al. (1972), the 1972 OBERS Projections (Bureau of Economic Analyses/USDC and Economic Research Service/USDA, 1972), and an article by W. Langbein in Pregel, et al. (1973) authoritatively show that urban land will increase from 19,000,000 to 32,000,000 acres by the year 2000. This urban land will encompass nearly 150 metropolitan areas where 70 to 75 percent of the nation's people will live. In addition there are 35,000,000 acres of irrigated land, mostly in the western United States, that should be surveyed periodically to estimate water requirements. This acreage is expected to increase to 40,000,000 acres by 2000. Other major water resource areas that need to be surveyed periodically are floodplains and wetlands because they are important ecological and recreation areas and regions where substantial damage may occur if industrial development occurs. We believe, therefore, that the annual savings of \$22 to \$23 million are conservative.

5.2 DERIVATION OF BENEFITS

The first task was to identify the expenditures devoted to land use or surface cover data gathering activities for water resource planning by federal and non-federal agencies. This involved studying the budgets of the federal agencies provided by the Office of Management and Budget (1975, 1976a). The federal users who were considered and for whom benefit estimates were made are the Army Corps of Engineers, the Soil Conservation Service, and the U.S. Geological Survey. Other, but smaller, federal water resource planning applications which were not considered were the Water Quality Administration, TVA, Bureau of Reclamation, Bonneville Power Administration, and the Forest Service. Potentially large, but less certain benefits also appear possible in the activities of HUD and the EPA. Again it was not possible to obtain any definitive data from these agencies to make estimates during this study, so they were not considered.

At the regional, state and local levels, hundreds of agencies are current or potential users. An estimate of their total budget was built up by considering requirements at five different levels of local government.

The next major task was to estimate the fraction of the data gathering budget which could be impacted by Landsat technology. The method used was an expert judgment based on knowledge of the scope and nature of the work involved. This judgment was provided by the Hydrology and Oceanography Branch at Goddard Space Flight Center, and by conversations with experienced and knowledgeable federal agency personnel.

The final task was to estimate the actual savings in the impacted portion of the data gathering budget. Representative documented cases where remote sensing approaches had been compared to conventional approaches were used as guides and benchmark situations. These studies indicate that where data are being gathered and prepared for use in watershed models or water demand models, reductions in cost to do this job can go as high as 80 percent when a fully experienced group is doing the remote sensing data preparation (Ragan and Jackson, 1975; Ragan, 1976). In this report a 70 percent cost reduction factor was used. Where a simple inventory and display of land use or surface cover information was all that was needed, a 25 percent cost reduction was used. For more extended discussion of the applications and savings due to the use of remote sensing one should review the study report prepared by the Applications Survey Group Inland Water Resources Panel (1976).

In the last part of Section 5.3 the programs of the state and local agencies are discussed. The total land use and surface cover data collection budget, the fraction of the budget that could be impacted by Landsat data, and the fraction of that which could be saved by using Landsat data are estimated. This leaves aside future growth of the programs and counts nothing for the compounding of benefits that can often be achieved by reinvesting the cost savings in other parts of the programs. Results are therefore minimum benefit estimates.

5.3 APPLICATIONS AND POTENTIAL BENEFITS

5.3.1 Army Corps of Engineers

Four activities identified in the annual budget of the Corps of Engineers involve systems planning activities where savings could be achieved using Landsat data. The first of these is the "Urban Studies" program conducted under the budget category "General Investigations." About 30 studies are on-going at any one time, each covering the water problems of a metropolitan area and requiring about four years to complete. The total budget for these studies is currently

\$19 million per year, of which \$3 to \$4 million is used for data collection and interpretation. Landsat data could impact an estimated 25 percent of the data collection effort by providing land cover information needed for hydrological models, and save an estimated 50 percent of the cost of this information (see Table 5.1).

Table 5.1

Applications and Potential Benefits
(\$ Millions)

	Budget Data	Landsat Impactable Portion	Cost Savings
Army Corps of Engineers			
Urban Studies	3-4	0.75-1.0	0.37-0.50
Flood Plain Management	2-3	1.0-1.5	0.7-1.05
Hydrological Models	3	0.75	0.52
Advance Engineering and Design	5-6	1.0-1.2	0.4-0.48
Soil Conservation Service			
River Basin Surveys	2.5	0.5	0.25
Small Watershed Investigations	4-5	0.6-0.75	0.3-0.37
Snow Surveys	0.75	0.37	0.25
Flood Hazards Investigations	1.0	0.5	0.35
Geological Survey			
Water Resources Investigations	50	2.5	1.2
Regional, District and Local Agencies			
Overall water planning, and planning of specific water resource projects	N.E.*	25.5**	17.8**
		33.4-34.6	22.1-22.8
*Not estimated. Landsat-impactable data costs estimated directly. **These numbers include contributions toward these efforts by HUD, The Water Resources Council, EPA and other Federal agencies.			

The second major category is the "Flood Plain Management" studies, also part of "General Investigations" and budgeted at \$11.3 million annually. These studies provide detailed maps of flood-prone areas. The data collection part of this budget represents \$2 to \$3 million annually, of which 50 percent is impactable with Landsat data. The estimated cost saving from using Landsat for the data would be 70 percent.

The third category is the hydrological modelling effort under "Research and Development," with a data budget of \$3 million. About 25 percent of this is impactable with Landsat data, with a cost savings of 70 percent.

Finally, Advance Engineering and Design, budgeted at \$27 million annually, has a data collection cost of approximately \$5 to \$6 million annually. This effort provides preliminary project designs and cost estimates. We estimate a Landsat impact of 20 percent, with a cost savings for this data of 40 percent.

5.3.2 Soil Conservation Service

Four programs are of principal interest.

The first is the "River Basin Studies" program which provides general surveys of water supply, water quality, erosion, sedimentation, flooding potential, irrigation and drainage and other agricultural needs of an entire river basin. Typically 50 to 60 of these studies are in process at any one time. About \$2.5 million of the \$16.4 million annual budget is used for data gathering, of which about 20 percent would be Landsat impactable. The cost savings potential is estimated to be 50 percent.

The Small Watershed Project Investigations and Planning program, budgeted at \$13.6 million, provides studies of smaller areas with a greater level of detail in planning and design than is the case for "River Basin Studies." About 180 of these studies are now active, with several thousand awaiting funding. The estimated data collection portion of the budget is \$4 to \$5 million of which 15 percent is estimated to be Landsat impactable, at a cost savings potential of 50 percent.

The Soil Conservation Survey conducts a program of snow surveys to determine the water yield from the snow-pack in northern and western agricultural areas. The data gathering cost of this program is estimated to be \$750 thousand annually. Landsat data is capable of impacting half this amount, with an estimated cost savings of 70 percent.

Finally, the Flood Hazards Investigations program, with a data gathering cost estimated at \$1.0 million annually, offers the prospect of 50 percent impact with Landsat imagery. The estimated cost saving potential is 70 percent.

5.3.3 Geological Survey

The U.S.G.S. conducts a \$56 million program of Water Resources Investigations to produce data and information relevant to flow and sediment discharge of rivers, location and quality of underground waters, and chemical quality and temperatures of water sources. The program includes research on water occurrence, water movement, the interaction of water with the environment, and techniques for measuring water data.

About 90 percent of the budget is spent for data gathering. However, because of the fact that physical samples are often needed, the Landsat impact would be less than in applications mentioned earlier. Five percent is used with a cost savings potential estimated at 50 percent.

5.3.4 Regional, District and Local Agencies

The University of Maryland (Inland Water Resources Panel, 1976) has conducted a study of regional, district and local activities in water resources planning and the analysis procedures are as follows.

The times required to complete individual tasks are extensive. There appear to be no data on the frequency of such studies on a national basis. In developing an estimate of the times and costs involved on a national basis a start was made by considering the 56 Standard Metropolitan Statistical Areas (SMSAs) that have populations in excess of 500,000. Within these SMSAs there are 174 county governments, 2,902 municipal governments, 1,470 township governments, 3,844 special districts, and an additional 2,486 special water-related districts dealing with flood control, water supply, drainage, etc.

Experiences with the counties surrounding Washington, D.C. indicate that approximately 150 man-days per year are devoted to land cover determinations and parameter estimates associated with urban water resource developments. If an hourly rate of \$8.00 is assumed, which would account for a \$1 million annual expenditure by the 56 SMSAs.

Municipal governments probably invest very little in this type of work. Therefore, we assume that the 2,902 municipal governments expend no more than 10 man-days per year, or \$640 per organization. However, the municipal governments within the 56 SMSAs are a very small fraction of the national municipal governments. Therefore, we assume that the SMSA municipal governments account for only 25 percent of the national expenditures. Therefore, municipal governments, nationally, are spending in the vicinity of \$7 million annually on studies that could be done by remote sensing.

Township and special district governments probably represent a very small investment. If we assume they use no more than five days per year and, as before, that the SMSA units account for only 25 percent of the national, the expenditure by these township and special district governments would be in the vicinity of \$4.9 million per year.

The water-related districts probably use in the vicinity of 30 man-days per year, or \$1,920 per agency. It is probable that the water-related districts in the 56 SMSAs are substantially larger than those in the remainder of the national scene. Therefore, we assume that expenditures of the 2,486 districts within the 56 SMSAs account for 50 percent of the total annual expenditure. Therefore, \$9.5 million is being expended annually by these organizations.

This analysis gives the total expenditures to be impacted as indicated below:

Counties	\$ 2,230,000
Councils-of-Government	1,500,000
Municipal Governments	7,400,000
Township-Special Governments	4,900,000
Water-Related Jurisdictions	9,500,000
	\$25,530,000

Detailed studies which involve small watersheds are not suitable candidates for Landsat interpretation, and are excluded from the above figures. The large aggregate amounts cited above result from the numbers of jurisdictions, even though only a small number of days per year may be spent by any one jurisdiction in gathering the land cover data that Landsat can supply.

The case studies for the Anacostia Basin and in Northern Virginia referenced earlier in the Ragan and Jackson (1975) and Ragan (1976) studies indicate the cost savings that can be expected in typical regional and local planning studies. Both studies show that by using Landsat imagery, interpreted with commercially available automated classification systems, a cost savings of 70 percent can be achieved. We apply this 70 percent cost savings estimate to the \$25.5 million now spent by regional, district and local agencies on obtaining and processing the types of data for which Landsat imagery would be suitable and the result is given in Table 5.1.

Estimates of all data collection and interpretation costs, the potential Landsat impact and the likely degree of cost reductions are summarized in Table 5.1. The dollar values shown in Table 5.1 follow from the budgets and percentages discussed above. These estimates are minimal in the sense that the agency survey is not all-inclusive, and the benefits from earlier project completions or

reinvestment of cost savings are not included. Furthermore, benefits derivable at the state level are not included, as no survey at this level has yet been completed.

6. WATER RESOURCES MANAGEMENT

6.1 INTRODUCTION AND SUMMARY

Landsat data can provide an important input to streamflow forecasts used in the management of dams and reservoirs. This input is the areal measurement of the snow cover in the local drainage basin. The snow cover information can improve flow prediction which in turn will effectively increase usable water for power generation and irrigation. The annual value of the improved information is \$13 - \$41.6 million for basins in the western United States.

Three connections must be made to verify that Landsat can produce benefits in water impoundment. First, the area in a river basin which is covered by snow must be an important piece of information for the efficient management of reservoirs since snow-covered area is the data that Landsat can collect. Second, the use of Landsat data must improve streamflow forecasting capabilities since this is the mechanism for generating the benefits. Third, the results of the forecast improvement must be reduced to a dollar value.

6.2 THE SNOW-COVERED AREA VARIABLE

The importance of snow-covered area to the accuracy of streamflow predictions has been based on a statistical analysis of 18 to 20 years of streamflow data and prediction errors for two river basins in California, the Kern and the Kings. The technical detail of this work is presented in the appendix to this chapter.

The analysis had two important conclusions. First, not all reservoir systems can profit from using Landsat snowcover data, but those that can will make significant reductions in the average level and variability of flow forecast errors. Second, the types of basins amenable to the use of snowcover data can be characterized by their general topography, the distribution of precipitation within the basin and the adequacy of the existing data presently used in forecasting. This second result allows the benefits obtained for the Kings and Kern River Basins to be extrapolated to California and then the western United States.

The first result was obtained independently by a group working within NASA and the private consulting firm Sierra Hydrotech. The second result is principally the work of Sierra Hydrotech. Having established the positive impact on forecasting errors for streamflow of a snow-covered area variable, the next link is the degree of impact that Landsat will create.

6.3 THE BENEFIT MECHANISM

Streamflow data is utilized by reservoir managers to adjust flood control safety margins. The accuracy of the streamflow has a direct bearing on the size of the margin. If an improvement in forecast accuracy occurs, then a dam manager can decrease his flood reservoir space in the reservoir and he can also better regulate spillage from the dam. The net result of such activities is an increase in the usable water at the dam. The value of the extra water is created as it is used either in the generation of electricity or in irrigation of agricultural land.

6.4 CAPABILITIES

The analyses performed on the streamflow forecasts for the Kern and Kings Rivers in California indicated that the inclusion of snow-covered areas as a variable with an accuracy attainable by the Landsat/Thematic Mapper system had the following impact. The mean error of forecast is reduced approximately 30 percent and the variability of the error is reduced by about 10 percent for the Kern River. The inclusion of snow-covered area did not result in a reduction of forecast error or in the variability of the error for the Kings River Basin. The details of these determinations are shown in the Technical Appendix.

Sierra Hydrotech investigated the differences between the Kings and Kern basins to discover what factors characterize those basins as amenable or not amenable to forecast improvement through use of amenable data. Basins where improvement will occur can be described by the following:

- Topography - Inhomogeneity of the distribution of area with elevation
- Precipitation Distribution - Uneven distribution of the amount of precipitation with elevation
- Poor quality of existing precipitation data

By classifying all the other river basins in California by these criteria into the two classes which are exemplified by the Kern and Kings Rivers, the capabilities derived above can be extrapolated to the entire state of California. Expressed in terms of an increase in usable water, Landsat data with Thematic Mapper accuracy will produce approximately a 185,000 acre-foot increase annually for the state of California. Sierra Hydrotech and Dr. A. Rango of NASA/GSFC carried out the extrapolation. The details are in the appendix.

An approximate extrapolation to eleven western states was carried out by Dr. Rango. He classified the states into groups, each of which was hydrologically

similar to California. The groups were:

- Arizona, Utah and Nevada
- New Mexico and Colorado
- Wyoming and Montana
- Washington, Oregon and Idaho

The extension of the capabilities to the western United States was then refined on the basis of relative cloud cover, climatology and irrigation/hydropower activity among the groups. The extrapolation factors developed are 2.31 for irrigation and 6.41 for hydropower. A detailed discussion of the derivation of the extrapolation is in the appendix.

6.5 BENEFITS

The last step in the development of the benefits of Landsat data to water resources management is the imputation of a dollar value to the increase in usable water that results from the improved flow forecasts. Since there are two major uses for the water, its value is dependent upon its ultimate use.

To determine the value of irrigation water, an average cost per acre-foot of water for the California Aqueduct was computed. The Department of Water Resources of California provided the required information in its Bulletin No. 132-75 and the figures are presented in the appendix. Weighing the costs at each juncture of the aqueduct by the volume of water estimated to be delivered to that juncture in 1976, an average cost of irrigation water of approximately \$60 per acre-foot was derived.

The value of an acre-foot of water used in the generation of electricity was approximated using a conversion factor of the energy value of the water to an equivalent amount of oil. The factor used was obtained in conversations held at the California Department of Water Resources. It was one acre-foot of water $\approx$ 10 barrels of oil. Conservatively valuing oil at \$5 per barrel gives an acre-foot value of \$50 for hydropower usage.

Due to the nature of reservoir operations, it is unlikely that all of the increase in usable water resulting from improved flow forecasting would be captured for economical use. In discussions between Sierra Hydrotech, the California Department of Water Resources and Dr. A. Rango of Goddard, an efficiency figure of 0.5 was agreed to as best approximation.

The computation of the benefits is now straightforward.

- Irrigation

Value for California = (Increase in volume in acre-foot) × (value per acre-foot) × efficiency factor

$$= 185,000 \text{ A.F.} \times \$60/\text{A.F.} \times 0.5 = \$5.5\text{M}$$

Value for West = $\$5.5\text{M} \times 2.31 = \12.7M

- Hydropower

Value in California = (Increase in volume) × (Value/A.F.) × efficiency factor

$$= 185,000 \text{ A.F.} \times \$50/\text{A.F.} \times 0.5 = \$4.5\text{M}$$

Value in West = $\$4.5\text{M} \times 6.41 = \28.9M

Since some but not all the increase in water can be used for both hydropower generation and irrigation due to timing incompatibilities, the actual value of the benefit must be between that obtained if only one use is considered and if both uses are considered. That is, the benefit for improved flow forecasts due to Landsat data is in the range of \$12.7M to \$41.6M.

6.6 OTHER BENEFITS

The benefits that were quantified in this section were based solely on the hydropower generation and irrigation applications. There are clearly additional uses for water, however, we were unable to compute the associated benefits within the constraints of this study. For informational purposes the major benefit areas which have not been quantified are flood control, recreation, navigation, and domestic and industrial water supplies.

APPENDIX

TECHNICAL RATIONALE

FOR

SNOW-COVERED AREA

TECHNICAL RATIONALE FOR SNOW-COVERED AREA

This section presents the rationale for translating snow-covered area measurements into improvements in forecast accuracy and water usage revenue.

SNOW-COVERED AREA IMPORTANCE

The melting of the snowpack in the Spring is the source of greater than 50 percent of streamflow in most areas of the western United States (Committee on Polar Research, 1970 and Rooney, 1969). For example, about 75 percent of the runoff in the Colorado River originates from snowmelt in key basins that represent only 13 percent of the contributing land area (U.S. Department of Interior, 1970). The early prediction of the amount of runoff to be derived from the snowpack allows more efficient utilization of the limited water supply for power generation, irrigation, flood control, domestic and industrial water supplies, and recreation. Historically, the Soil Conservation Service has prepared seasonal snowmelt runoff forecasts for western river basins that have been extremely useful for water management purposes. For the western United States, error in seasonal runoff forecasts prepared on April 1 ranges from 7 to 40 percent, with an average of approximately 18 percent (U.S. Department of Interior, 1974).

These discrepancies are due to forecasting errors inherent in the procedures used and to errors resulting from variations in the weather after April 1. The forecasting errors result from uncertainties in point measurements of snow water equivalent which are commonly used as indices of basin-wide snowmelt runoff in prediction equations. The errors in predicted runoff tend to be largest in years of unusually heavy or light snowpack accumulation.

Observations of the areal extent of the snowpack have long been recognized as an important (but difficult to obtain) hydrologic parameter related to both the average snowpack water equivalent and the snowmelt-derived runoff. The U.S. Army Corps of Engineers (USACE) in the Northwest and the Salt River Project in Arizona have in the past flown low altitude missions in order to measure snow cover areal extent to aid in their runoff prediction responsibilities. The rate at which the snow cover depletes is an index which is inversely related to the snow water equivalent and the generated snowmelt runoff. As the snow leaves the low elevations of the watershed, the hydrograph begins to rise and continues to do so until the snowpack area reaches a critical value where meteorological snowmelt conditions cannot produce ever increasing amounts of runoff. The hydrograph then begins to recede until the remaining snowpack disappears and the runoff is maintained by baseflow. The slower the snowline retreats up the watershed to the elevation where the hydrograph starts a downward trend, the greater the resulting runoff volume and, usually, peak flow.

By knowing the snow-covered area, the area of the watershed representative of conventional snow water equivalent measurements can also be inferred. This allows the objective extrapolation of water equivalent values over an entire watershed rather than a rough approximation obtained by a single arithmetic averaging. Further refinement permits the combination of water equivalent and snow-covered area data to calculate existing snow volume by elevation zones. Such determinations are required by various numerical models and permit the most sophisticated use of snow-covered area for runoff predictions. By more accurately characterizing and locating the available snow water volume, remote sensing derived snow-covered area measurements can be used to improve forecasts of seasonal flow. A study on the Kings and Kern River watersheds in California was conducted so as to show the magnitude of possible forecast improvement on two dissimilar basins as a result of the incorporation of SCA into forecast procedures.

The fact that snow-covered area can reduce standard error of forecasts when included in prediction procedures becomes important in conservation and availability of water. When water operators and users are assured of a more accurate snowmelt runoff forecast, more multiple uses of the existing water supply are possible. Hence, the water supply is effectively increased. For example, a portion of water that would normally be held in a reservoir for late season irrigation or power requirements could be released for early season irrigation or domestic supplies because the reservoir operator would be more confident that additional water would be forthcoming. Additional revenue would consequently result when more of the existing supply was utilized.

In order to test how much of an improvement in forecast accuracy might result from the use of snow-covered area data, the two watersheds in California were tested. Both the Kings and Kern Rivers in the Southern Sierras had relatively long-term aircraft snow-covered data (18 - 20 years) in addition to the full complement of conventional data. The conventional data were obtained from the Snow Surveys Branch of the California Department of Water Resources and the aircraft snowcover data from U.S. Army Corps of Engineers. Conventional techniques for the prediction of seasonal flow on both watersheds were examined and the aircraft snow-covered area data were combined with the conventional data set for each available year. Various techniques for incorporating snow-covered area into the conventional prediction methods were investigated. The general approach was to include snow-covered area with various combinations of conventional parameters in regression analyses and compare the results of predictions for certain control years with techniques not using snow-covered area.

This study was initiated for the purpose of determining the impact of snow-covered area, as mensurated by Landsat, on forecasting seasonal streamflow. The Kern and Kings River basins in California were analyzed in detail. The conclusion of the study was that including snowcover data in the water runoff model reduced the average error of the Kern River basin forecast by 29 percent and the standard deviation of the errors by 8 percent, while the forecast error and standard deviation of the errors of the Kings River basin remained at approximately their current level. These studies are discussed in the following.

The California Department of Water Resources supplied eighteen years of data for the following variables for the Kern River basin:

- Y = April - July Runoff
- X_1 = April 1 High Elevation Snowpack Index
- X_2 = October - March Precipitation Index
- X_3 = Previous Year April - July Runoff
- X_4 = April - June Precipitation Index
- X_5 = April 1 Low Elevation Snowpack Index
- X_6 = May 1 Snowpack Index
- X_7 = May 1 Snow-Covered Area in Percent of Basin

The model currently being used does not use snowcover data; it is of the form $Y = AX_1X_2 + BX_3 + CX_4 + DX_5 + EX_6 + F$.*

A new model utilizing snowcover data, $Y = AX_2X_7 + BX_1 + CX_6 + D$, was found by using a step-wise regression analysis on the given data and various combinations of the data. The statistics for the two models are:

	<u>Current Model</u>	<u>Snowcover Model</u>
R^2 Value	97.9	98.4
F-test Value	156.0	355.3
Standard Error of the Estimate	35.6	30.5

Both models were exercised to determine which would provide the better forecast. Since the number of available data points was limited and several variables were being considered, a series of regressions were used to make the forecasts. This technique consisted of deleting the year to be forecast from the data

*A, B, C, D, E, F are regression coefficients.

base, deriving the regression equation from the remaining data, and then making a forecast for the deleted year. The absolute value of the difference between the forecast and the actual runoff represented the error of the forecast. The forecast and forecast error were then computed for each year. The average and the standard deviation of the errors were calculated, resulting in the following table:

	<u>Current Model</u>	<u>Model with Snowcover Data</u>	<u>Improvement</u>
Average Forecast			
Error	40.11	28.67	29%
Standard Deviation			
of Forecast Errors	25.28	23.31	8%

The snow cover model has two terms not in the current model - the variable with snowcover data included and the April 1 high elevation snowpack index variable used alone. To be certain that it is the variable with snow cover data, and not the snowpack index variable, causing the improvements, two tests were made. First, the current model with the snowpack index variable added (FORM I) was run and showed that this addition to the current model would not result in the improvements noted above. In addition, step-wise regression analysis was applied to the given data and various combinations of the variables, excepting those involving snowcover data. A model (FORM II), $Y = AX_1X_2 + BX_6 + C$, resulted. These two models were each exercised using the forecasting technique described above. In both cases the model with snowcover data gave better results as seen from the table below:

	Form I	Form II	Model with Snowcover Data
Average Forecast			
Error	38.33	35.67	28.67
Standard Deviation			
of Forecast Errors	27.01	27.29	23.31

The same type of analysis was done with data for the Kings River. The Department furnished twenty years of data for the following variables:

Y = April - July Runoff

X_1 = April 1 Snowpack Index

X_2 = October - March Precipitation Index

X_3 = Previous Year April - July Runoff

X_4 = April - June Precipitation Index

X_5 = May 1 Snow-covered Area in Percent of Basin

The model which is now used by the department is:

$$Y = AX_1 + BX_2 + CX_3 + DX_4 + E.$$

The regression study of the variables selected a model that incorporated the snowcover data; it is: $Y = AX_4 + BX_2 + X_5 + C$. The statistics of the two models are:

	<u>Current Model</u>	<u>Snowcover Model</u>
R^2 Value	97.1	95.9
F-test Value	161.3	218.4
Standard Error of the Estimate	120.9	145.7

For the reasons noted above, both models were run using the series of regressions for forecasting. In this river basin the addition of snowcover data did not improve the forecasts. Both the average error and the deviation of the forecast errors remained at the present level.

	<u>Current Model</u>	<u>Model with Snowcover Data</u>
Average Forecast Error	114.9	120.9
Standard Deviation of Forecast Errors	106.4	107.7

The logical question now is why does snowcover data bring about an improvement in forecast accuracy in the Kern River basin but not in the Kings River basin. The explanation is discussed in the following section.

Although there has been no exhaustive research regarding the relatively better performance of the Kern River procedures compared to the Kings River procedures, the following are suggested as probable causes. These probable causes might represent criteria for selecting watersheds where areal extent of snowcover might prove a valuable parameter in reducing forecast error as the snowmelt season progresses.

1. Inadequate or unrepresentative precipitation data. Precipitation during the snowmelt season is probably measured less representatively

on the Kern River than on the Kings River. April precipitation, averaging over 10 percent of the seasonal total, may possibly be partially described in terms of areal extent of snowcover as the melt season progresses. It is suggested that watersheds which lack adequate or representative late season precipitation measurements might benefit from areal extent of snowcover.

2. Topography. The Kings River distribution of area which elevation is relatively homogeneous with areas between 6 and 12 thousand feet distributed uniformly (Figure 6.1). Average April 1 snowline on the Kings is 6,500 feet. The Kern River, with an average April 1 snowline of 7,000 feet (Figure 6.2), appears to have a substantial portion of the area between 7 and 9 thousand feet. It is suggested that watersheds with relatively large portions of the area confined to given elevation zones may respond more readily to analysis utilizing areal extent of snowcover.
3. Precipitation Distribution. The Kings River apparently has a relatively uniform distribution of precipitation with elevation. The Kern River, on the other hand, may have average annual precipitation of 40 inches or more at 9,000 feet in one portion of the basin and as little as 15 inches at the same elevation in other portions of the basin. This distribution may vary considerably from season to season. It is suggested that areal extent of snowcover as the melt season progresses may provide an index to the distribution of precipitation and snowpack quantities throughout the basin.

The combination of precipitation distribution and area-elevation distribution in a given watershed could provide an index to the probable effect of areal extent of snowcover in updating forecasts of runoff volume. Sparseness of other data types might also be a consideration.

Other major water yielding basins in California were investigated in regard to these possible causative parameters. The area/elevation plots of some of these watersheds are shown in Figures 6.3 - 6.11. Based on the same considerations used for explaining the Kern/Kings difference, it was estimated that snow-covered area would be a major factor in reducing snowmelt runoff forecast error on at least 11 of 22 major basins in California as shown in Table 6.1. The standard error can be decreased for May 1 forecasts on the order of 170,000 A.F. in California using snow-covered area. If a 9-day coverage from the Thematic Mapper is available, a small improvement (about 10 percent) in forecast accuracy could be realized increasing the total to about 185,000 A.F. It is further estimated that 50 percent of this decreased standard error or about

92,500 A.F. of usable additional water annually can be realized by more efficient utilization as a result of improved forecasts in California. This water can be used for either irrigation and/or power.

To allow extrapolation to the entire eleven western states, state groupings were constructed that could be compared to California on the basis of cloud cover and climatology. The cloud cover and climatology considerations were used to develop empirical factors that expressed the likelihood of Landsat realizing the benefits in each of the state groupings that were estimated in California. California was given an empirical factor of 1.00. The state groupings and their cloud cover and climatological empirical factor are as follows: 1) Arizona, Nevada, and Utah (1.15); 2) Colorado and New Mexico (0.85); 3) Wyoming and Montana (0.50); and 4) Idaho, Washington, and Oregon (0.33).

To compare the importance of irrigation and hydropower in California with the rest of the West and thus provide a basis for extrapolating the California benefit estimates, state group withdrawals for irrigation and hydropower were compiled from van der Leeden (1975). The total withdrawals for each group were multiplied by the cloud cover and climatology factor and compared to the California irrigation or hydropower withdrawal as shown in Table 6.2. Totaling the rest of the West and comparing it to California, irrigation relative importance is 1.31:1 and hydropower relative importance is 5.41:1. These conversion factors, developed on the basis of cloud cover and climatology and the importance of irrigation and hydropower, are used to extrapolate the California benefits to the remaining western states.

The computation of the value of water used for irrigation purposes is based on figures presented in Bulletin No. 132-75 of the California Department of Water Resources. The unit dollar figure obtained is a weighted average of costs to all the reaches of the California Aqueduct. The cost at each reach is weighted by the volume of water delivered to the reach. Table 6.3 presents the figures used for each reach of the Aqueduct, the volume of water delivered, cost per acre-foot and the total cost.

The total volume estimate for 1976 for the entire system is approximately 1.3M acre-feet. There are 37 reaches receiving this water at an average of 35,000 acre-feet each. The average cost per reach was calculated to be slightly more than \$2M. So the average unit cost of an acre-foot of water delivered along the Aqueduct worked out to \$57.72/Acre-Foot or approximately \$60/Acre-Foot.

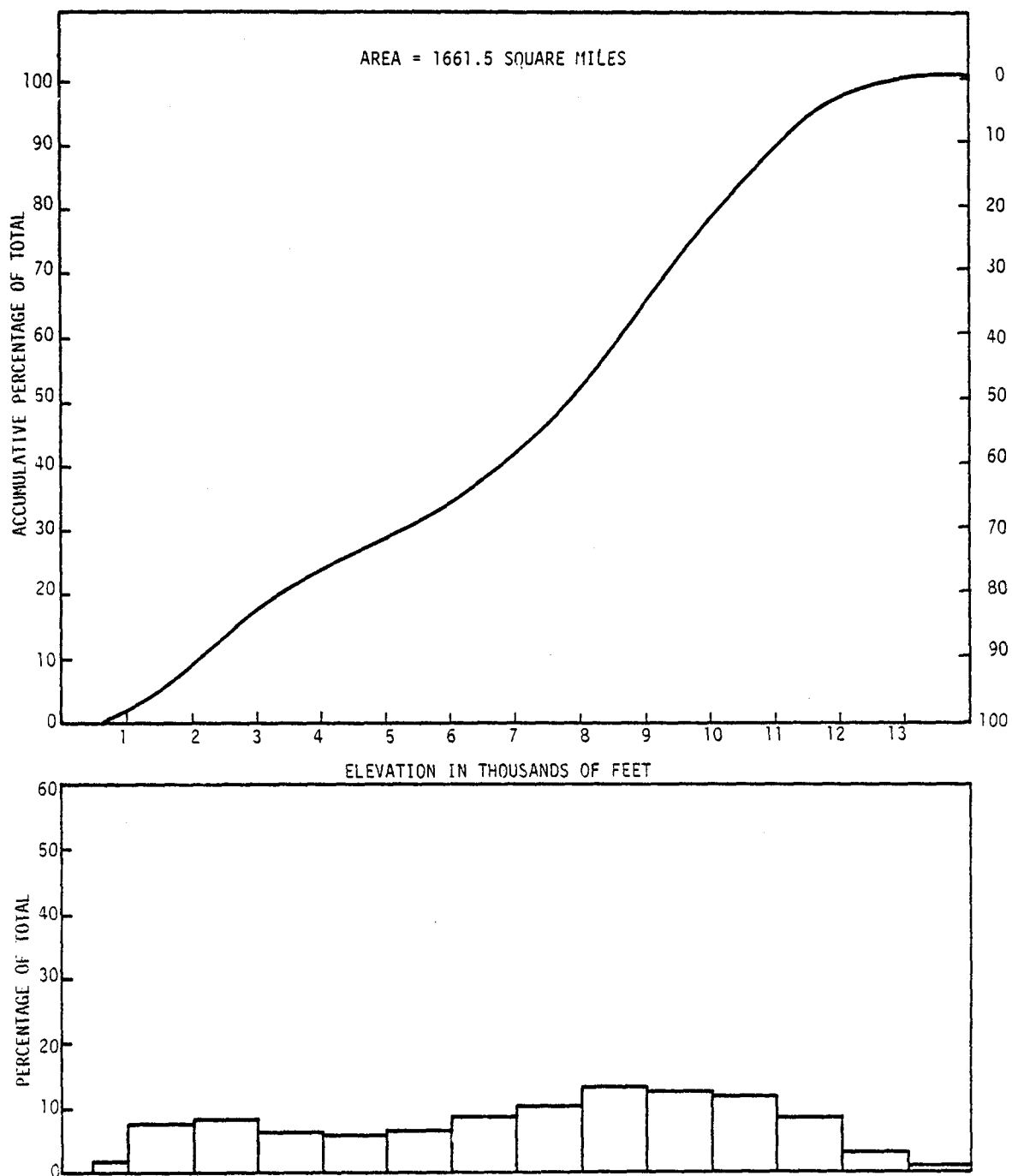


Figure 6.1. Kings River at Piedra

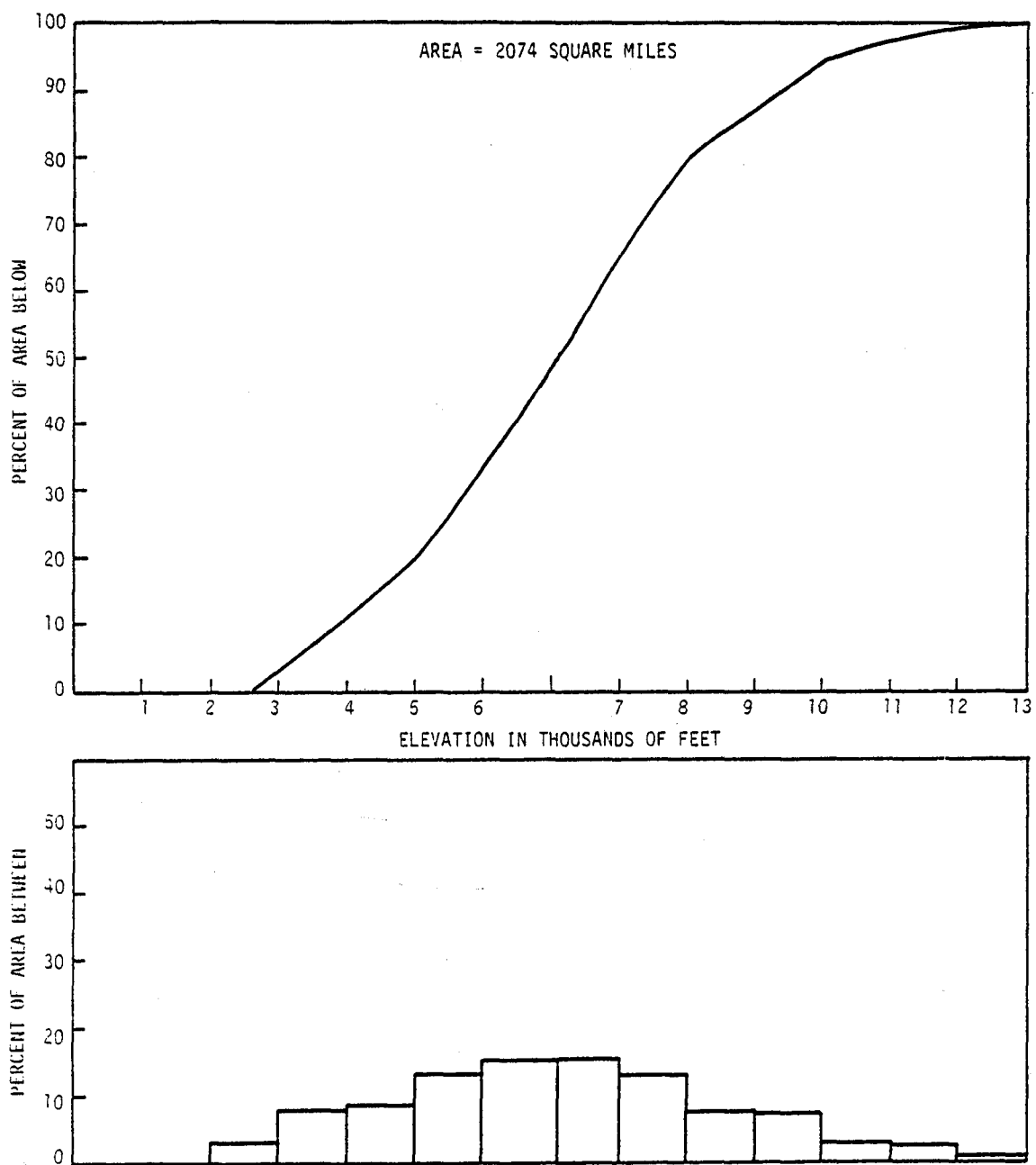


Figure 6.2. Kern River Inflow to Isabella

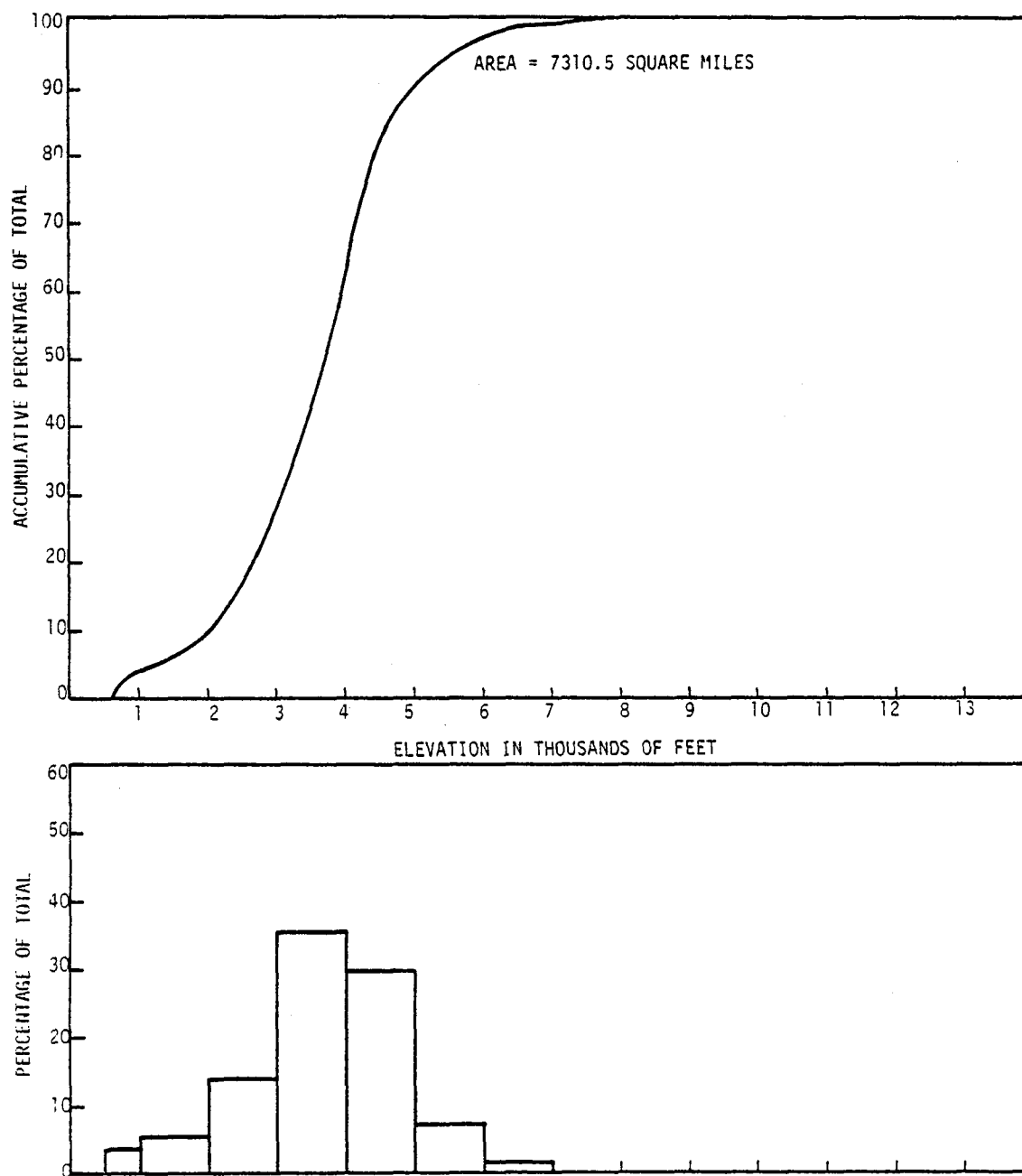


Figure 6.3. Sacramento River Inflow to Shasta Reservoir

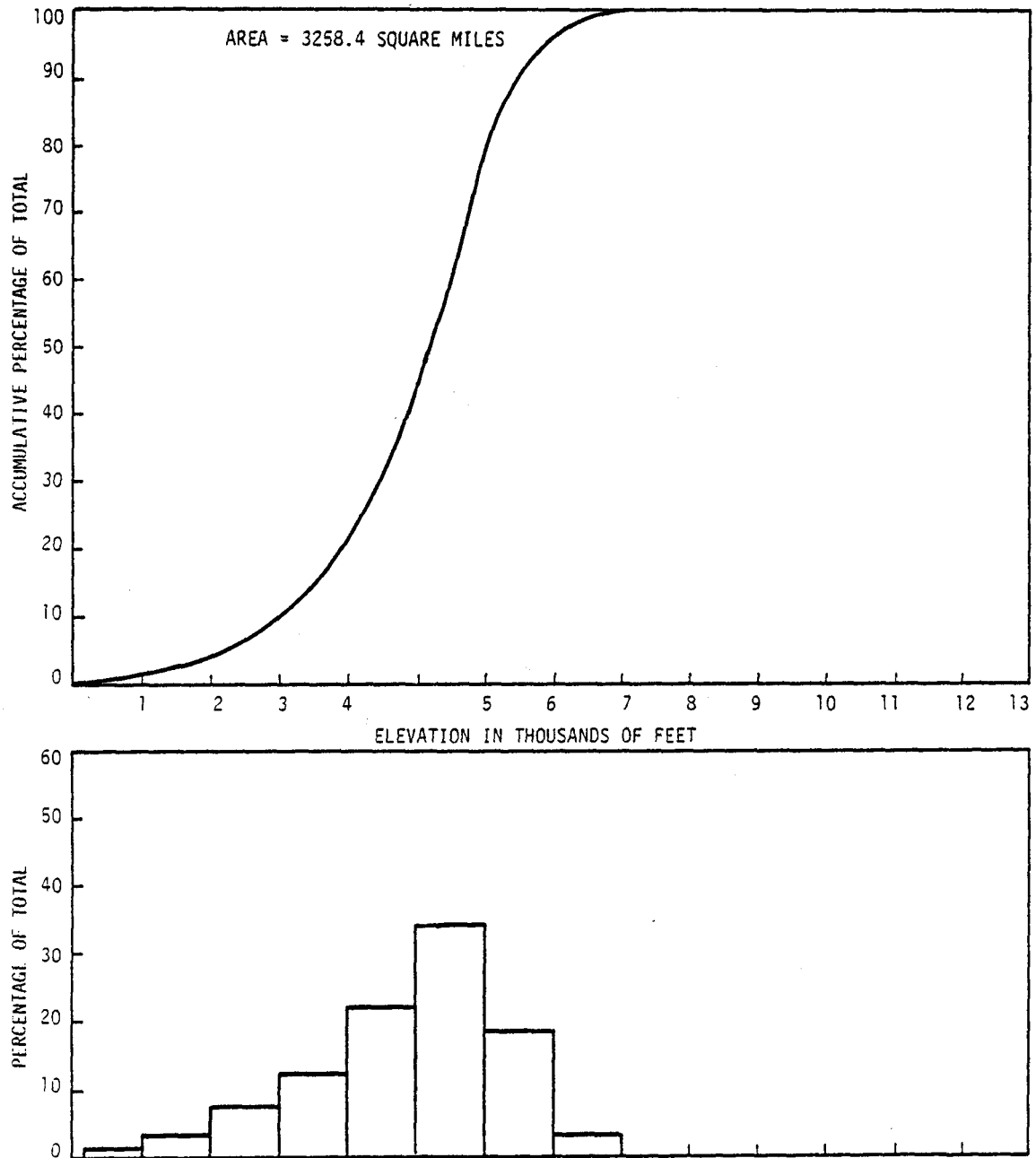


Figure 6.4. Feather River at Oroville

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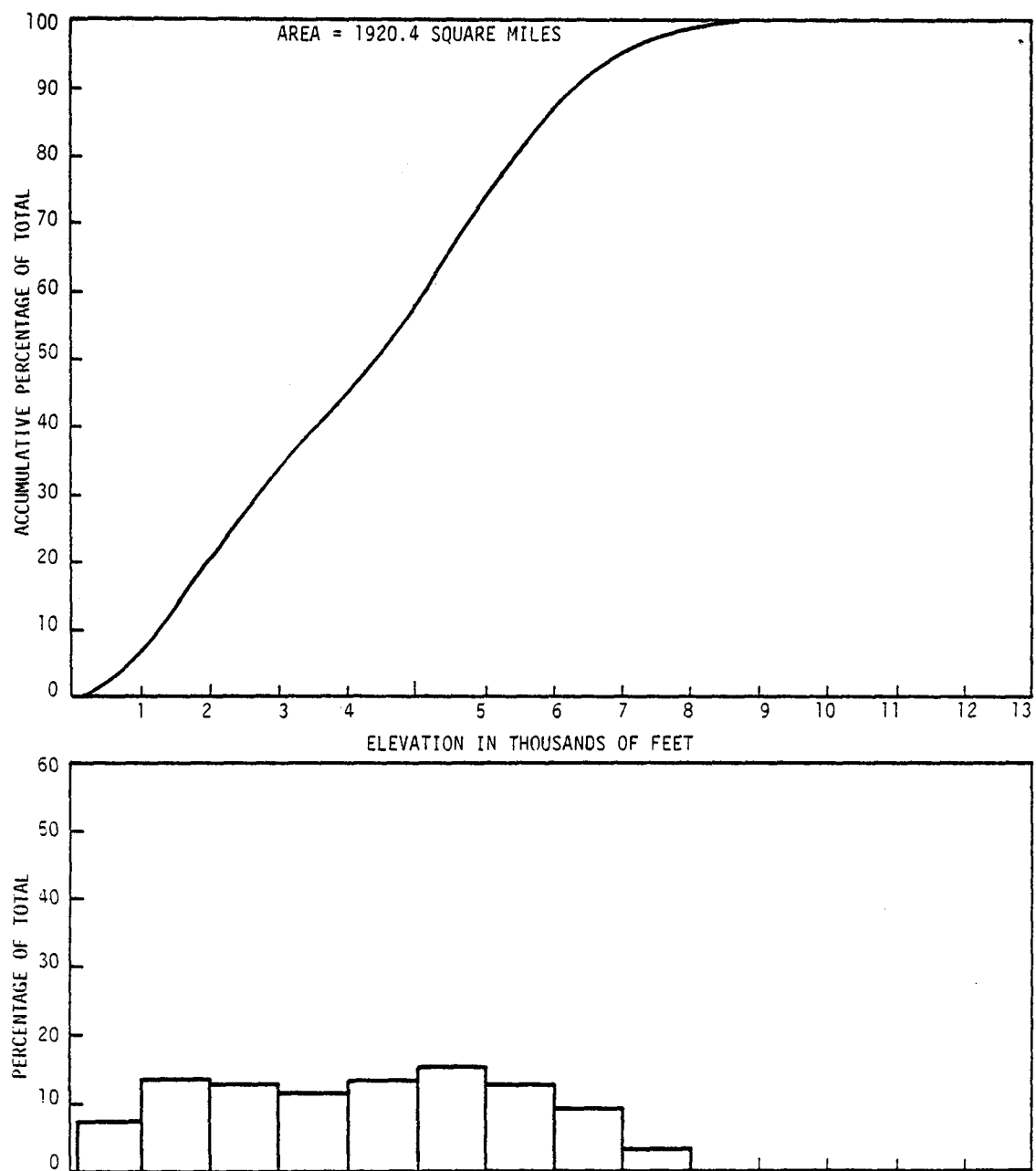


Figure 6.5. American River at Fair Oaks

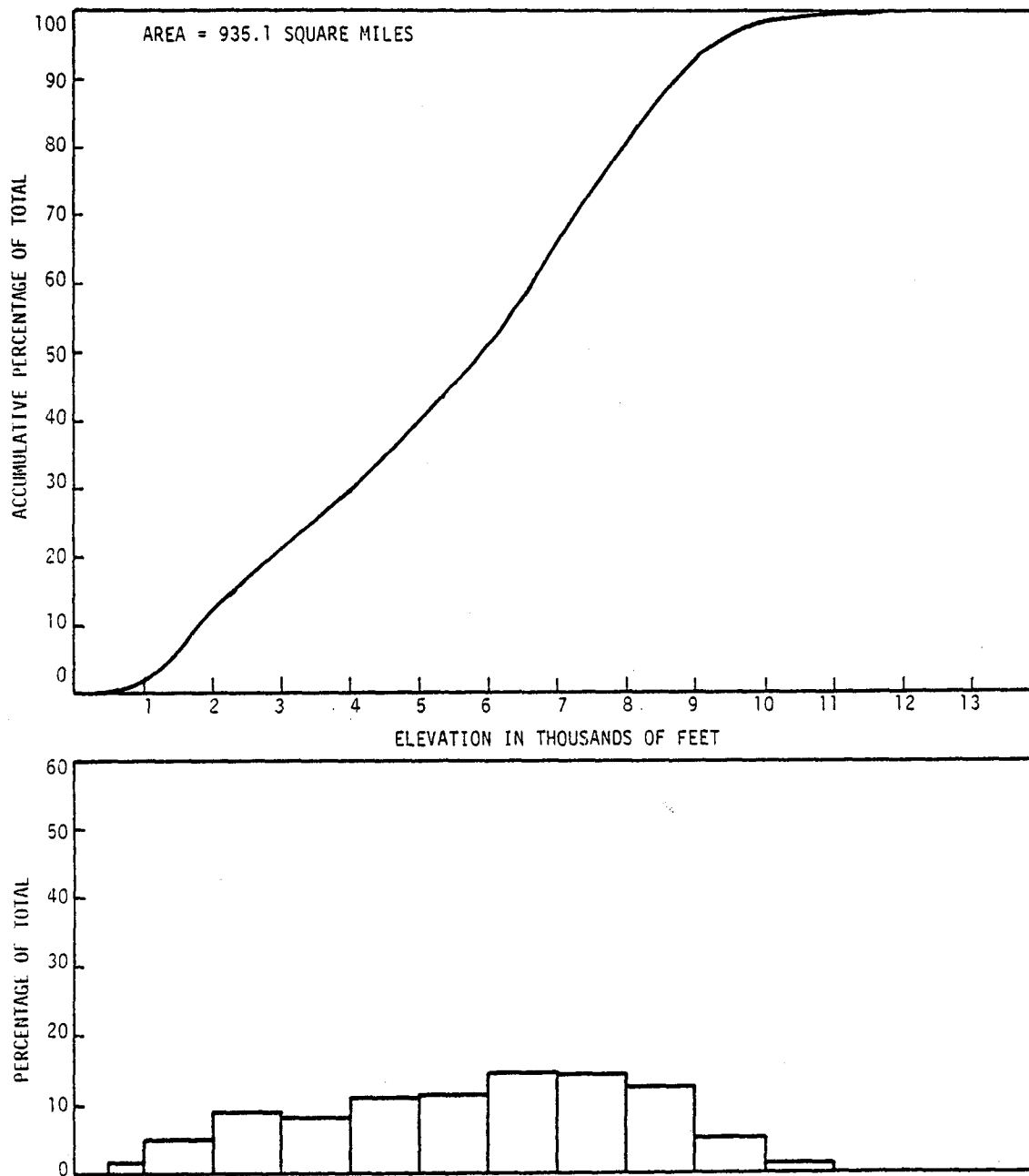


Figure 6.6. Stanislaus River Below Melones Power House

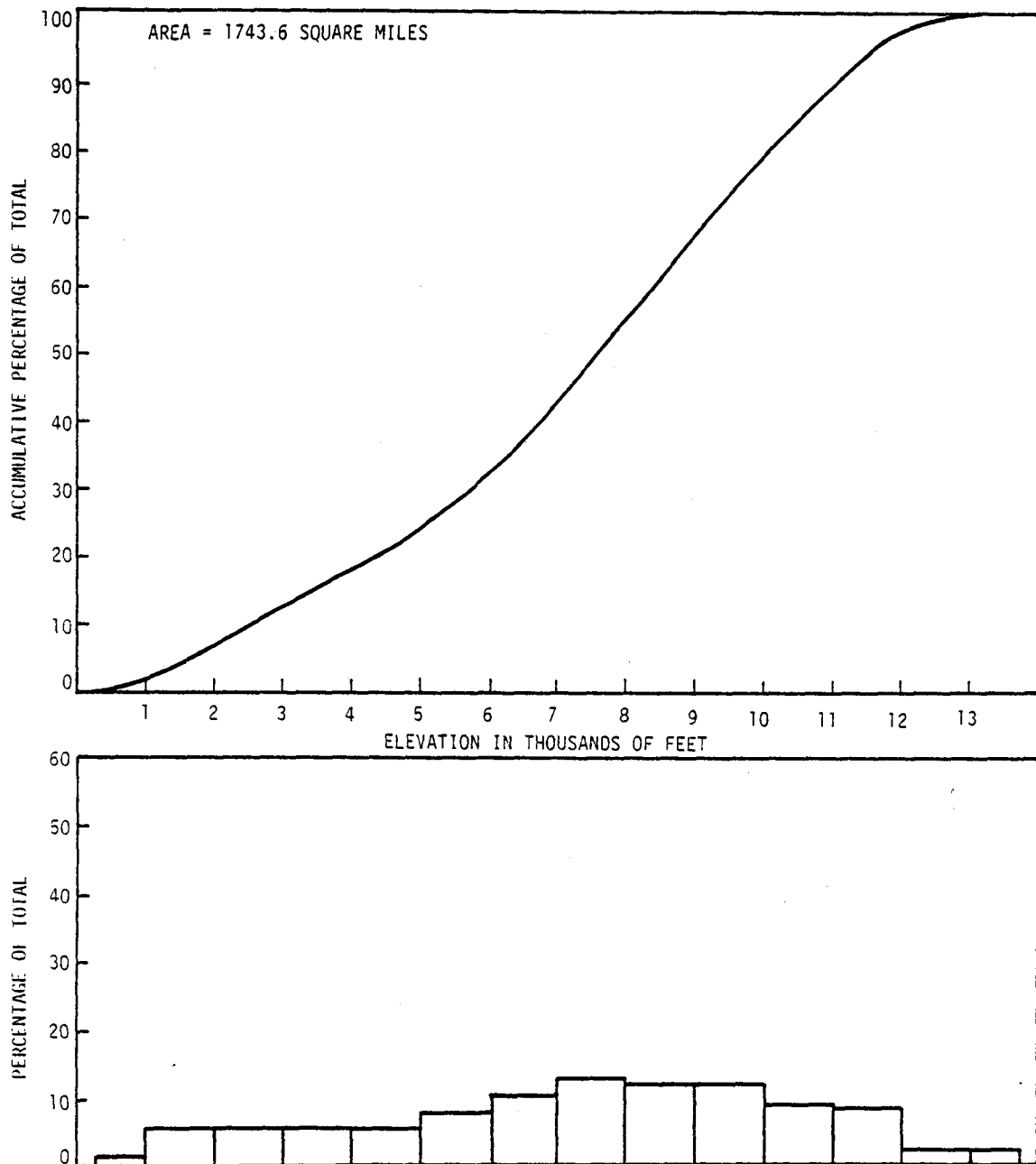


Figure 6.7. San Joaquin River at Friant

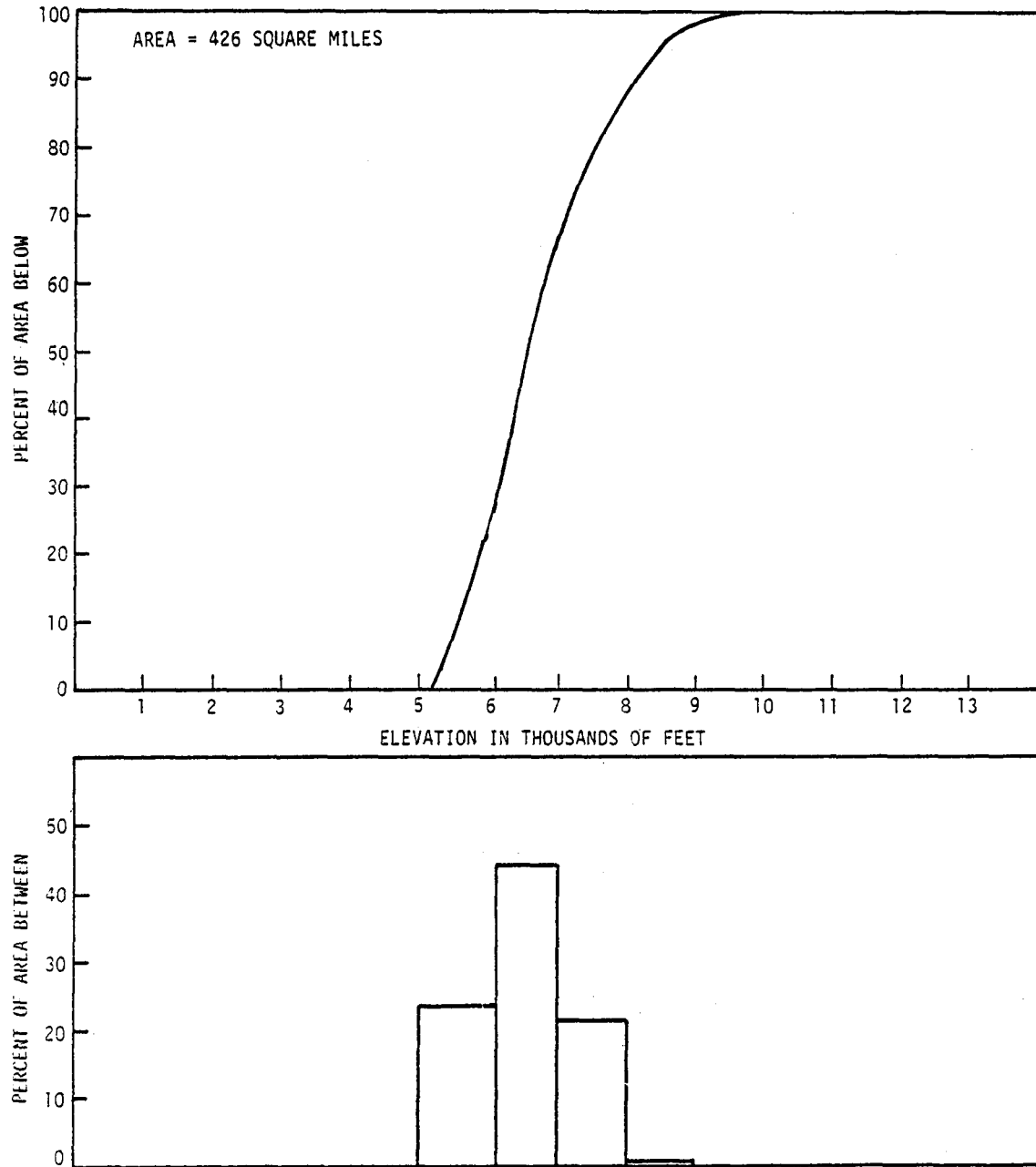


Figure 6.8. Truckee River - Tahoe City to Farad

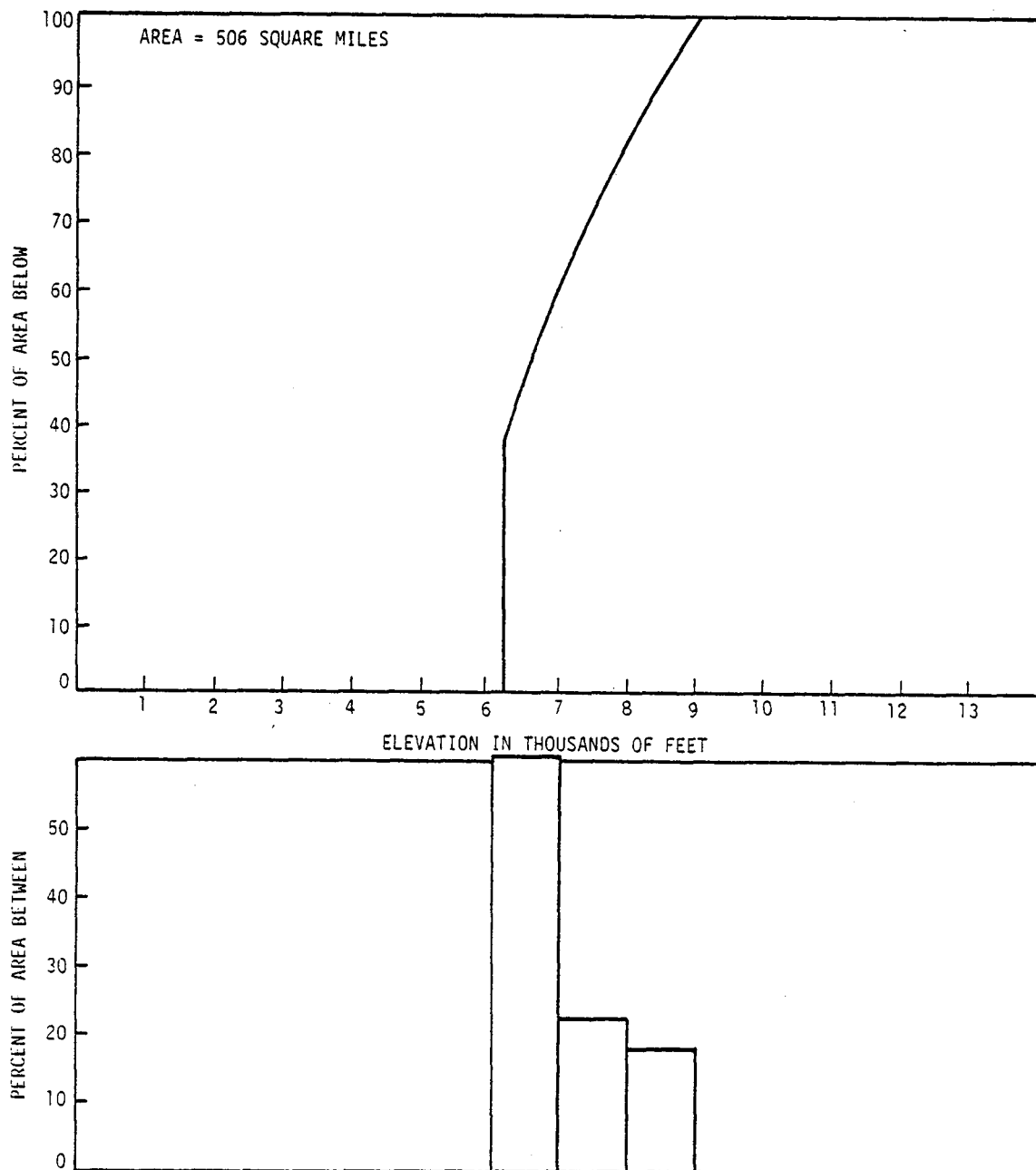


Figure 6.9. Truckee River at Tahoe City

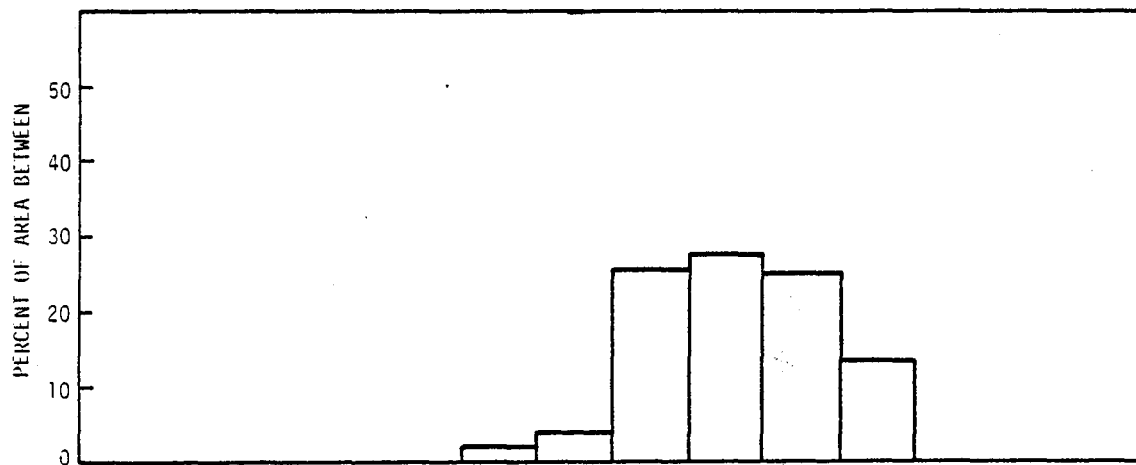
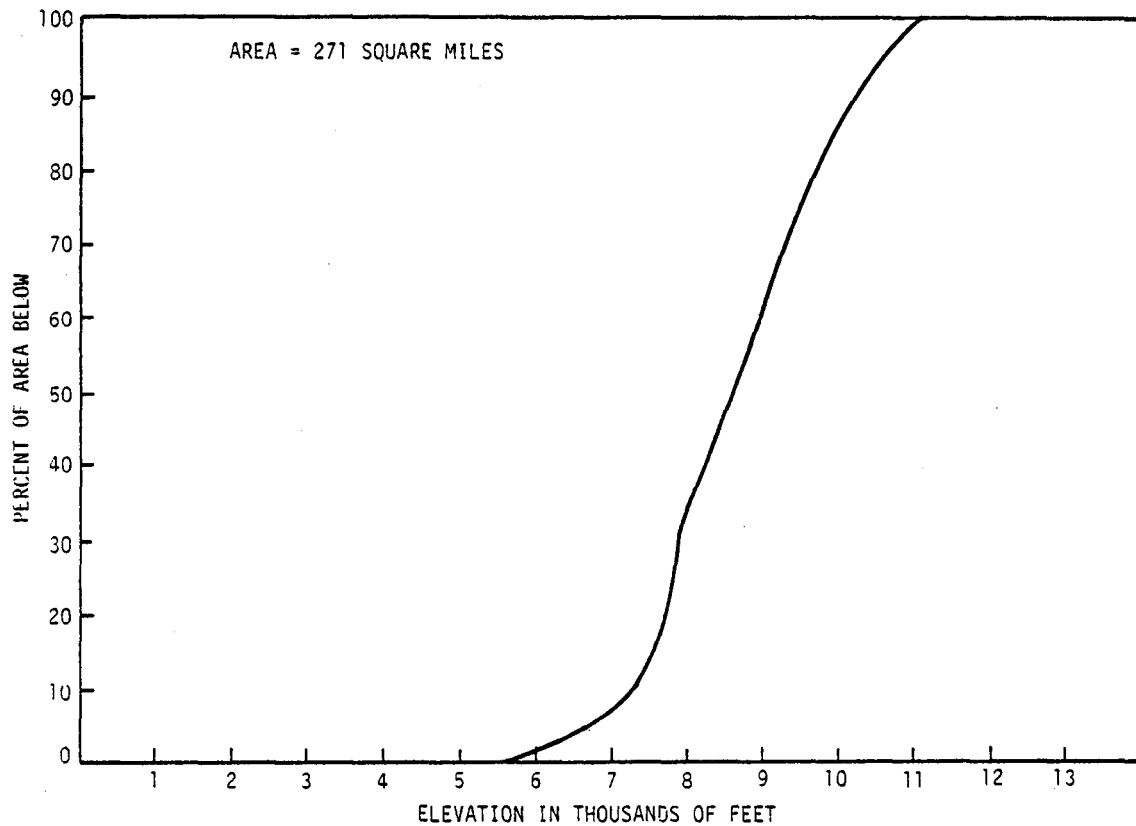


Figure 6.10. West Walker River near Coleville

C-2

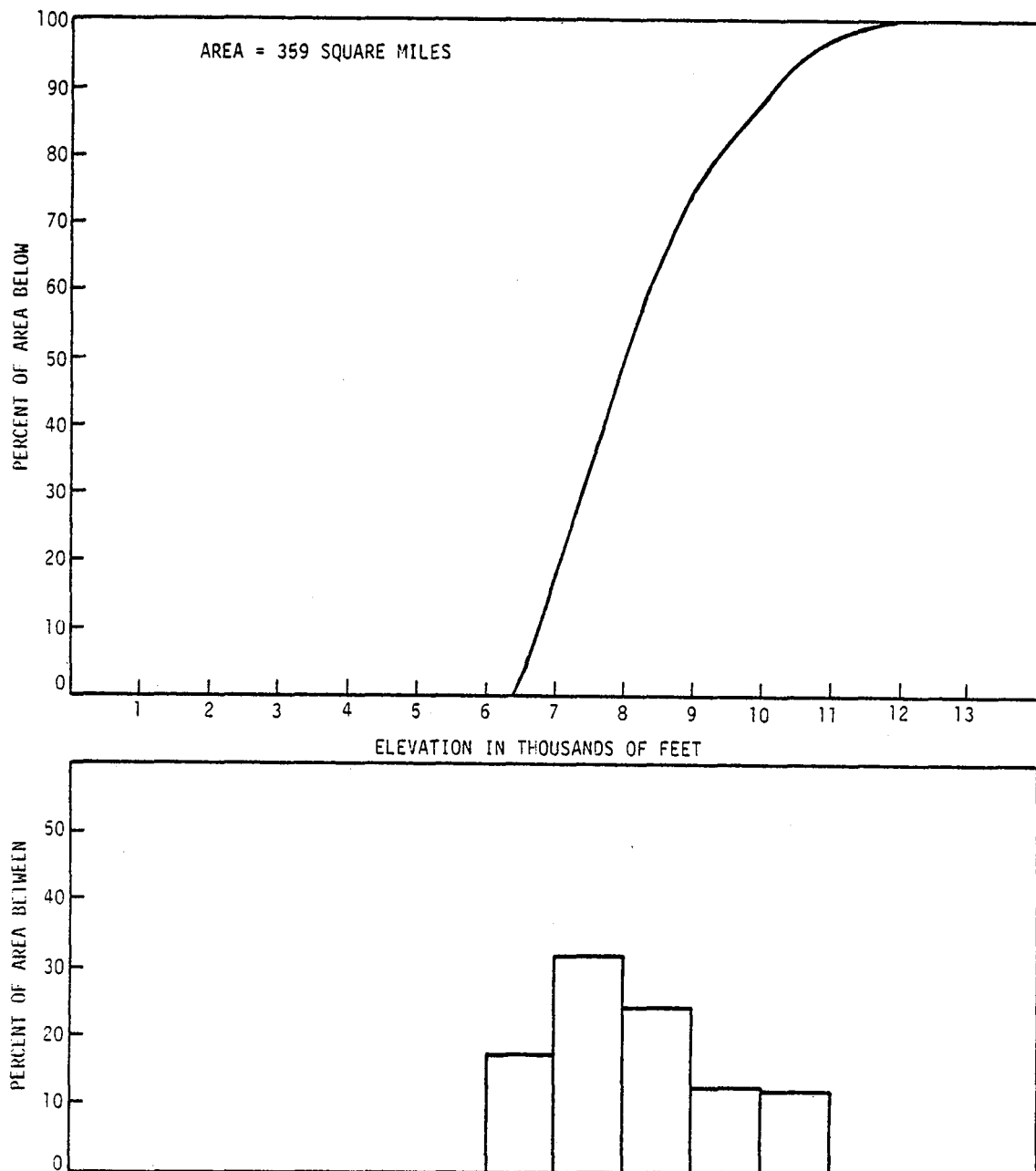


Figure 6.11. East Walker River near Bridgeport

Table 6.1

Estimates of Increased Forecast Accuracy for Forecasts by CDWR Based on May 1st Update, June 28, 1976

Stream	Average Apr.-July Runoff A.F.	Standard Error 1000 A.F.	Standard Error %	Estimated Decrease S. E. %	Estimated Decrease S. E. 1000 A. F.	Estimated Decrease S. E. % A. S.	Remarks
Trinity	617.3	41.6	6.7	15.0	6.2	1.0	
Sacramento:							
Sacramento	285.0	28.4	10.0	30.0	8.5	3.0	Likely prospect for large base flows
McCloud	420.0	46.0	10.9	30.0	13.8	3.3	
Pit	1,013.0	95.0	9.4	30.0	28.5	2.8	
Feather	1,862.0	179.0	9.6	30.0	53.7	2.9	
Yuba	1,081.0	77.4	7.2	15.0	11.6	1.1	
American	1,321.0	78.0	5.9	15.0	11.7	0.9	
Total	5,982.0	503.8	8.4		134.0	2.2	
San Joaquin:							
Mokelumne	466.0	22.8	4.9	0	0	0	
Stanislaus	717.0	47.4	6.6	0	0	0	
Tuolumne	1,236.0	55.6	4.5	0	0	0	
Merced	608.0	40.9	6.7	0	0	0	
San Joaquin	1,193.0	68.0	5.7	0	0	0	
Total	4,220.0	234.7	5.6				

Table 6.1 (Continued)

Stream	Average Apr.-July Runoff A.F.	Standard Error 1000 A.F.	Standard Error %	Estimated Decrease S. E. %	Estimated Decrease S. E. 1000 A. F.	Estimated Decrease S.E. % A. S.	Remarks
Tulare Lake:							
Kings	1,157.0	71.7	6.2	0	0	0	Test Watershed
Kaweah	270.0	20.6	7.6	0	0	0	
Tule	59.0	9.1	15.4	?	?	?	
Kern	420.0	43.2	10.3	40.0	17.3	4.1	Test Watershed
Total	1,906.0	144.6	7.6		17.3	1.0	
Sierra East Side:							
Truckee	309.0	20.4	6.6	30.0	6.1	2.0	High Eastern Portion Dry
Tahoe	174.0	12.0	6.9	15.0	1.8	1.0	
West Carson	51.0	2.6	5.1	15.0	0.4	0.8	
East Carson	181.0	18.4	10.2	30.0	5.5	3.0	High Eastern Portion Dry
West Walker	143.0	8.4	5.9	15.0	1.3	0.9	
East Walker	60.0	11.7	19.5	40.0	4.7	7.8	
Total	918.0	73.5	8.0		19.8	2.1	

Table 6.2

State Group	Average Irrigation Withdrawal (MGD)		Average Hydropower Withdrawal (MGD)	
	Actual	Corrected*	Actual	Corrected*
A. California	33,000	33,000	84,000	84,000
B. Arizona, Nevada and Utah	13,000	14,950	27,000	31,050
C. Colorado and New Mexico	16,000	13,600	5,000	4,250
D. Montana and Wyoming	13,000	6,500	76,000	38,000
E. Idaho, Oregon and Washington	25,000	8,250	1,154,000	380,820
*Corrected on basis of Cloud Cover and Climatology.				

Table 6.3

Reach	Water Volume (A.F.)	Costs/A.F.	Total Costs
1	590	\$ 22.07	13,021
2	0	29.49	0
3	2,700	97.81	264,087
1	265	24.29	6,437
2	5,444	25.18	137,080
4	2,894	27.56	79,759
5	2,026	32.03	64,893
6	6,571	32.26	211,980
7	12,526	34.05	426,510
8	8,774	36.67	321,743
9	88,000	42.11	3,705,680
2A	3,500	6.16	21,560
8C	29,500	11.46	338,070
8D	58,100	11.82	686,742
9	35,100	12.09	424,359
10A	88,068	12.39	1,091,163
11B	90,647	12.79	1,159,375
12D	0	13.17	0

Table 6.3 (Continued)

Reach	Water Volume (A.F.)	Costs/A.F.	Total Costs
12E	56,417	\$ 13.45	758,809
13B	11,668	14.05	163,935
14A	10,600	19.78	209,668
14B	27,000	20.14	534,780
14C	12,100	20.45	247,445
15A	15,700	25.94	407,258
16	7,700	36.47	280,819
17E	0	71.88	0
18A	2,000	74.33	148,660
19	7,000	76.03	532,210
19C	1,000	90.09	90,900
20A	2,000	77.58	155,160
20B	100	79.57	7,957
21	640	80.54	51,546
22A	1,400	81.25	113,750
22B	39,200	100.46	3,983,032
23	0	100.89	0
24	932	105.89	98,689
26A	365,240	98.60	36,012,664
28G	0	102.92	0
28H	20,600	107.01	2,204,406
28J	0	121.37	0
29F	50	82.56	4,128
30	350,700	82.92	29,080,044
31A	89,500	26.29	2,352,955
33A	0	126.73	0
34	0	133.09	0
35	0	153.18	0

7. FORESTRY

7.1 INTRODUCTION AND SUMMARY

Landsat can assist in the management of United States forests in a variety of ways, including estimation of timber inventory, hazard surveillance and damage assessment.

A quantitative study was performed of the benefits from timber inventory estimation, as applied to Forest Service lands in the South, the West and the Pacific Coast (ECON 1976). The approach is based on the 1972 Hayami and Peterson value of information paper. Improvement of information, applied to tree planting/harvesting decisions, was found to add \$5 million annually in value to the timber harvest while maintaining all nontimber values.

Benefits result from the fact that Landsat imagery can be used as the primary classification source for a stratified sampling of timber. The Remote Sensing Research Program at Berkeley (RSRP 1974) has shown that this can yield a 10 percent gain in accuracy or a 44 percent cost savings in Forest Survey work in a typical western forest. This implies that the inventory cycle of National Forest lands could be changed from once in ten years to once in 5 to 6 years, while maintaining current standards of accuracy and current budget levels. By speeding up the inventory cycle, the information on which decisions are based - and the decisions themselves - show marked improvement.

7.2 BENEFIT DERIVATION

A model of Forest Service timber management has been developed (ECON 1976) which will permit the estimation of the impact of improved information on the decisions that forest managers make on tree-planting/timber-harvesting. These decisions are of long-term importance because overharvesting impairs the reproduction rate of a forest, while underharvesting leads to lower growth rates. The model recognizes that the Forest Service must also take nontimber values into account, because it is mandated to recognize the values of standing trees for purposes of aesthetics, recreation, soil conservation and wildlife habitats.

The focus of the model is on the intermediate level of planting/harvesting decisions, involving allocations of planting and harvesting between forests of several hundred thousand to a few million acres. This would be a "subregion" to the Forest Service, and is regarded as the level at which Landsat data would have the greatest impact.

The model characterizes "information" by two major characteristics: timeliness and accuracy.

Decision making is simulated using optimization techniques - a dynamic programming formulation is employed. Each timber demand region is separately optimized in terms of the values of the timber in its subregions.

Three components are of importance. These are as follows:

1. A value function, which ascribes values to outputs and decisions. Values from forests accrue from both the timber harvested and from the timber not harvested. The timber value can be estimated from market data. The nonharvested timber provides values such as those cited above. The existence of positive value for standing timber per se is evidenced by the fact that the dollar return for federal timber, and the timber growth rates themselves, fall below the market rate of interest. If strictly market factors were permitted complete domination, our National Forests would be liquidated, as is acknowledged by Forest Service personnel. Nontimber values are assumed to persist in the future as in the past.
2. A state transformation. This describes how the forest inventory changes over time, as a function of region and volume of the standing trees, and the rate of harvesting. Tree growth data from the past are employed to derive the necessary constants.
3. An information descriptor. This describes the accuracy of knowledge of the standing timber volume at any time. This is a function of the accuracy of measurement of timber volume and growth, and the time elapsed since the last measurement. The mean value of the elapsed time since the last measurement, of course, depends on the frequency of measurements.

The model produces estimates of the total present value of the forest resource, region by region, as a function of

1. Accuracy of timber volume estimates
2. Accuracy of timber growth rate estimates
3. Accuracy of update of measurements

Three Forest Service regions were considered - Southern Pine, Western Pine and the Pacific Coast. Smaller Forest Service holdings in the northeast and

midwest, and hardwood forests were not studied. Private forest holdings were not considered as major beneficiaries because of their current intensity of management.

The major assumptions employed are as follows:

1. The social decision making mechanism (a Forest Service-Administration-Congress consortium) approximates optimal decision making, once all values, including the nontimber values, are considered.
2. Decisions are made on a region-by-region basis.
3. There exists approximate equivalence between NFS sales and harvests.
4. Current Forest Service capabilities are those characterized by the "Forest Survey Handbook," which calls for a ten-year rotating inventory of all forest lands, with a mean accuracy of + 5 percent of timber volume and timber growth in the South and + 10 percent in the West.

Table 7.1 presents a listing of the data inputs which were used in the NFS Management model in order to estimate benefits. Sources of data used and methods of estimation are cited.

7.3 RESULTS

The results of the application of this model to the Forest Service's National Forest System are summarized in Table 7.2. Annual benefits of \$5.9 million and \$7.2 million are shown for the Landsat-MSS and TIM systems, respectively.

Notice that these Landsat systems have the capability of providing greater accuracy at equal costs and frequency or greater frequency at equal cost and accuracy. These capabilities have been documented by the Remote Sensing Research Program at University of California, Berkeley study (RSRP 1974) in the Plumas National Forest in Northern California. There the Berkeley group reported that a 10 percent decrease in error or a 44 percent cost savings were possible by adding a Landsat-MSS system on to existing Forest Services practices. The 44 percent cost saving has been translated into a 40 percent increase in inventory frequency for use in ECON's benefit model. Attempts by RSRP to extend these results to the Sam Houston National Forest (Texas) in 1976 were unsuccessful and no advantage from the MSS system could be shown due to the fact that the Southern Pine stands there were less structured than those of the

Table 7.1

Inputs Used in Forestry Benefit Study		
Input	Source of Data Used	Method of Estimation
Regional elasticity of timber demand	Market and sales data from Forest Service and other demand studies	Regression
Elasticity of non-timber demand	NA*	Reasonable approximation based on observed public behavior
Timber growth rates by region	Forest Service	Regression
Current state of NFS Timber system	Forest Service	NA
Discount rate	Academic Literature	Consensus from other natural resource management studies
Variability of timber growth	Forest Service personnel	Consensus from discussions
Current NFS information capabilities	Forest Service	NA
Non-timber prices	Forest Service sales data	Use of NFS Management Model
*NA = Not Applicable		

Plumas NF. From these two studies, it is estimated that the 1974 study results apply to all western forests and that no benefit from Landsat-MSS can be shown in the South. However, the increased spectral and spatial resolution of the TM system should be sufficient to extend the increased capabilities shown in the West to the Southern Pine region. The results reported in Table 7.2 reflect these capability estimates.

In addition to the \$5.9 million MSS and \$7.2 million TM annual benefits cited above for the regional level Forest Service timber inventories, some benefits should be attainable at the level of individual forests, and from other federal

Table 7.2

Estimated Annual Gross Benefits from Landsat-MSS and -TM Systems in National Forest Timber Sales Management				
Landsat-MSS System			Landsat-TM System	
Timber Demand Region	From Increased Measurement Accuracy	From Increased Frequency of Inventory	From Increased Measurement Accuracy	From Increased Frequency of Inventory
	Gross Annual Benefits, Millions of 1975 Dollars			
Southern Pine	None	None	0.63	1.27
Western Pine	3.96	3.83	3.96	3.83
West Coast	1.97	1.69	1.97	1.69
Total	5.9		7.2	

Estimated benefits based on softwood timber and volume and growth measurements only; see text.

System capability inputs from NASA, based on RSRP 1974 and RSRP 1976.

Benefits shown for increased accuracy and increased frequency are alternative benefits and are not additive. Benefits marked by underline are those used in calculating the total benefits.

lands such as those under the jurisdiction of the Bureau of Land Management, the Bureau of Indian Affairs, and the National Park Service. These additional benefits have not been quantified at this time.

Other Landsat forestry applications should also be of importance. These include surveillance of forests to detect areas of high fire hazard or susceptibility to pests or disease; or assessing the damage from fires, pests, disease, or floods. Although Landsat clearly is well adapted to these applications, the capabilities have not been thoroughly documented and benefit models have not been developed for them as yet.

8. LAND USE PLANNING AND MONITORING

8.1 INTRODUCTION AND SUMMARY

The land use planning and environmental monitoring applications of Landsat are extremely diverse, and represent at least \$15 million and more likely \$48 million in annual benefits. The lower value is based on the estimated cost of obtaining Landsat-equivalent land use data on a once-a-year basis for the entire United States; this is considered to be a very conservative statement of the actual requirement. The \$48 million value is the estimated cost of obtaining such data four times annually, which is more likely to satisfy the differing seasonal requirements of the different users of the data.

Land use data of the type available from Landsat are useful as a basis for legislative and policy decisions, for project planning, for zoning and permit granting, for detection of unauthorized or conflicting uses, for research and assessment of current problems, and for early warnings of future problems. The user community consists of hundreds of federal, state, regional and local agencies, as well as academicians, planners, contractors and consultants. The users referred to here, of course, are additional to the users associated with the specific applications discussed in other chapters, such as agricultural crop information, oil and mineral exploration, water resources and forestry.

The land use planning-monitoring community has traditionally been forced to take data from diverse and often outdated sources, or else to incur the costs of aerial surveys. The use of existing data sources has proved to be very expensive, because of the labor required to select, combine, interpret and update the sources, and code the information in a usable form. Updating ordinarily requires searching records, performing site visits and reducing the results to the common format. Special purpose aerial surveys and interpretations of the resulting images are also expensive. Pooling of efforts is difficult to achieve.

Landsat's benefit derives from replacing these piecemeal efforts with a data product that is uniform, current and capable of automated interpretation. Its value can be assessed at a minimum as equal to the cost of obtaining such a product by the least cost system that would satisfy the combined needs of land use planning and monitoring agencies. This would be a national, airborne surveillance system, such as has been suggested from time to time by various informed observers, among them OMB (1972).

The benefits, \$15 to \$48 million per year, are based on the cost of operating such a hypothetical system, with the required frequency of total U.S. coverage — estimated in a later section to be from once to four times per year.

8.2 DERIVATION OF BENEFITS

The system posed as the least cost alternative to Landsat as a land use data source is one based on the U-2 high-altitude reconnaissance aircraft. The U-2s are assumed to be equipped with instruments producing the same spectral bands and resolution as the Landsat Thematic Mapper, and to be based at five strategic places in the continental United States and Alaska. Their flights would be planned and coordinated so as to take advantage of good weather, with the objective of producing cloud-free imagery of all parts of the United States with a frequency of once per year at a minimum and four times per year at a maximum.

The aircraft system must be operated in certain ways to provide imagery comparable with Landsat imagery — some sidelay must be provided to compensate for flight path errors, the viewing angle must be within approximately 25° of the vertical, and the time of day of imaging must be within 1 to 2 hours of the time of Landsat passover. The exact rigidity of these restrictions is a function of the terrain steepness, and has been taken into account in computing aircraft system costs. It has also been necessary to make allowance for the time each aircraft loses in climbing to or descending from altitude and in cruising to the starting position for imaging, as well as the reflights that become necessary because of equipment malfunctions or cloud cover losses. Prior U-2 imaging experience has been useful in making the necessary adjustments. Aircraft are assumed to be operated up to 700 hours per year, in order to permit necessary scheduled and unscheduled maintenance. Existing U-2s are not assumed to be included in this program because of inadequate payload capabilities, but only enough U-2s are purchased to obtain the necessary imagery without exceeding the maximum yearly flying hours per aircraft.

The aircraft system cost elements are as recorded in Table 8.1. These figures are largely derived, as indicated, from NASA Ames Flight Center experience. The major exception is the data processing cost figure, which includes the cost of radiometric and geometric correction of the data, as well as land use classification and limited mosaicing of the images into useful scenes. The cost of this data processing was determined by a special study which took into account the hardware and software requirements for performing these functions for low and high data-rate aircraft systems. The special study was performed in a manner that makes these costs comparable with the Landsat data processing costs for purposes of computing net benefits.

Table 8.1

Aircraft System Cost Elements		
	Values Used (1976 \$)	Source of Data
CAPITAL COSTS*		
Aircraft	\$9,000,000	Current Ames estimates are \$7-10 million based on lot buys.
Sensors (per aircraft)	\$1,000,000	Derived from Texas Instruments bid on Ames MSS procurement, modified upwards 4X for added requirements.
Set-Up Cost	\$4,630,000	Ames A/C Support Study (1973), inflated at 8% annually to 1976 and adjusted for # bases.
Set-Up Cost (per aircraft)	\$ 310,000	
FIXED ANNUAL COSTS		
Bases	\$ 610,000	Ames FY 75 experience, inflated. A/C-related costs include fixed base costs. Costs based on 700 hour per year usage level.
Aircraft (per aircraft)	(per aircraft)	
VARIABLE ANNUAL COSTS		
Flying (per flight hour)	\$ 1,510	Ames FY 75 experience, inflated.
Data Processing (per data hour)	\$ (3,000) (Correction only; classification considered same as for Landsat)	No reliable data source has been found; existing MSS experience based on experimental operation of 24-channel instrument flown at 10-12,000 feet.
*Annualized at 10% rate.		

The cost of operating a U-2 surveillance system are shown in Table 8.2. These figures are consistent with the unit costs shown in Table 8.1, and the attainable scheduling and operating efficiencies, reflight rates and rates of imaging new terrain.

Four scenarios are shown:

1. Annual coverage — summer months
2. Annual coverage — winter months
3. Semiannual coverage — summer and winter
4. Seasonal coverage

The two cases of greatest interest are numbers 2 and 4. These represent the minimal versus the more adequate satisfaction of the data resource needs of the land use planning-monitoring community. The range of costs — and therefore the benefits from having the Landsat data instead — is \$15 to \$48 million annually.

8.3 DATA REQUIREMENTS OF THE LAND USE PLANNING-MONITORING COMMUNITY

As indicated above, it is essential to determine the frequency and timing of the demand for land use information by the land use planning and monitoring community in order to measure the benefits of Landsat data. Owing to the diffuseness of the user community, and some uncertainties regarding the classification capabilities of Landsat with the Thematic Mapper, it is difficult to characterize this demand precisely. Some factors are operative that permit us to estimate the upper and lower bounds of demand, however. A lower bound for demand may be taken as annual coverage of the terrain, preferably taken at a time of maximum visibility of features, such as after leaf-loss in autumn, but before the first snows have fallen. This lower bound follows from several independent reasons:

1. ECON (1974) identified 25 separate statutory reporting functions, each representing an average annual coverage of about ten percent of the United States land surface. Taken together, and discounting for overlap, ECON concluded that a statutory requirement existed in 1974 for at least annual 100 percent coverage of the United States land surface.

Table 8.2 Aircraft System Annual Costs (\$ Millions)

Scenario	Coverage	A/C Required	Capital Cost	Flight Cost	Data Cost	Total Cost
1	Once annually June, July, August	5	5.46	4.39	4.69	14.54
2	Once annually November - March	6	6.48	4.06	4.31	14.85*
3	Twice annually June - August, November - March	7	7.50	7.89	9.00	24.39
4	Four times annually June - August, September - November, December - February, March - May	14	14.65	15.26	18.05	47.96*

* Bounding cases for "minimum" and "adequate" land use coverage

2. Particular review functions of federal agencies, such as the review of environmental impact statements, wetlands development permits, or applications for variances from environmental pollution requirements, can only be conducted within the intent of the law if reasonably current data, not more than a year old, is employed.
3. The state and regional planning officials interviewed in connection with this study indicated that a year was typical time frame for most of their planning projects, and that data on land use should not be more than a year old at the time it is introduced into the studies, if at all possible.

At the opposite extreme, a case might be made for seasonal — four times a year — coverage requirements developing in the early 1980s as the full capabilities of the Landsat Thematic Mapper system become known. Such a demand for seasonal coverage need not imply that very many, or even one user, make use of all the data. Instead, seasonal coverage would provide each user with the capability to select the data taken at the time most appropriate to his own peculiar planning or monitoring need. Delineation of vegetative types is clearly done better during the green season, but man-made improvements are ordinarily seen better when leaves are off. Snow enhances the visibility of some features, but interferes with others. If seasonal coverage were provided, it seems likely that some users would make use of nearly every season of coverage.

For purposes of this study, therefore, we have assumed a range of demand between one and four times annually for total United States coverage. Benefits are calculated in accordance with these limits.

9. SOIL MANAGEMENT

9.1 INTRODUCTION AND SUMMARY

Landsat Follow-on is expected to contribute significantly to soil management by speeding the preparation of soil base maps, by observing the time and place of soil loss and by detecting the place and degree of soil nutrient deficiencies.

Of these benefits, however, only the first has been quantified. By reducing the cost and accelerating the production of soil base maps for the 1.3 billion acres not yet having such maps in the United States, annual cost savings of \$5.3 to \$8.8 million are anticipated throughout the 1980-1995 period. Further benefits, which are not quantified, will result from the earlier availability of the base maps. The base map program is discussed in the next section.

The benefits from observing soil loss and nutrient deficiencies are considered in Section 9.3, but estimates of dollar values are not yet available.

9.2 SOIL BASE MAPS

As of July 1, 1975, the date of the most recent accurate figures, there were 1.352 billion acres or 59 percent of the United States for which no soil surveys had been completed. The Soil Conservation Survey is engaged in a 20-year program to provide soil base maps for the remainder of the United States.

Landsat can reduce the time needed to produce a soil survey by defining soil boundaries in the planning stages of a survey. J. B. Peterson (1976) of the Laboratory for Application of Remote Sensing at Purdue University has estimated that 1 to 1-1/2 years can be saved from the normal 7 to 8 year period to perform a soil survey, with a proportionate reduction in cost. This amounts to a 12 to 21 percent reduction in the normal cost, which as of 1975, was \$0.75 per acre.

Under the SCS's 20-year program, about 57 million acres enter the planning stage each year, and will continue to do so until 1995. The estimated annual savings are therefore 12 to 21 percent of the \$43 million cost of performing soil surveys on these 57 million acres — or a \$5.3 to \$8.8 million annual benefit. We do not attempt to estimate the additional benefit of having the soil base maps available sooner than would be the case without Landsat, although it is worth noting that Klingbiel (1966) estimates that a soil survey repays its full cost within the first year after its completion.

9.3 OTHER BENEFIT AREAS

9.3.1 Soil Loss Studies

The Department of Agriculture (1965) estimated the annual United States soil loss to be \$1.6 billion during the period 1951-1960. At today's farm real estate values, such a rate of loss would be worth more than \$5 billion. Soil conservation measures may have served to reduce this loss somewhat, but the losses must still exceed \$1 billion annually.

The United States extends assistance in soil conservation in the form of technical extension services, tax deductions for conservation measures, cost sharing with landowners for specified conservation actions and government-funded research. These measures, in total, are estimated to cost several hundred million dollars per year.

Landsat is expected to increase the effectiveness of this program. Its capabilities include the ability to monitor sediment flow in waterways (Peterson, private communication). Experiments have not yet reached the point where benefits can be calculated, however.

9.3.2 Soil Nutrient Deficiencies

Deficiencies of nutrients in the soil cause crop production losses, relative to potential yields or quality. In one sorghum production area of 300,000 acres in Texas, Pennington (1976) has estimated that iron deficiencies cost \$8.6 million in annual crop production.

The extent of deficiency must be known to determine the quality of added nutrient that will produce optimal returns. Landsat is of value in determining not only the presence, but also the extent and degree of deficiencies. Gaussman (1975), for example, has shown that Landsat can detect the presence and areal extent of iron chlorosis in sorghum, due to iron deficiency in the soil. Again, however, the experimental program has not yet progressed to the point that definite benefits can be calculated.

In summary, a definite annual benefit of at least \$5.3 to \$8.8 million can be attributed to Landsat's capability for reducing the cost of soil survey work — with strong indications that large additional benefits may result from Landsat's capabilities for detecting and measuring erosive soil loss and soil nutrient deficiencies.

10. NON-QUANTIFIED BENEFITS

10.1 INTRODUCTION AND SUMMARY

In earlier chapters, we discussed Landsat Follow-on in terms of areas of application where both the systems capabilities had been demonstrated, and the economic benefits could be quantified. These are minimum benefits for those areas, because the assumptions chosen were consistently conservative. Furthermore, in many instances the quantifiable part of the benefit appeared to understate the full picture of benefits by a large factor.

In this chapter, we cover additional areas of Landsat Follow-on application that seem certain to be important. In these areas either a full definition of capability or a satisfactory economic model of benefits is still to be developed. Nevertheless, some idea of the probable importance and likelihoods of benefits can be presented.

Out of many areas that have been cited in the remote sensing literature, just four are selected for brief discussion here. These are as follows:

- Rangeland Management
- Crop Pest Management
- Construction Siting
- Global Environment Monitoring

They will be discussed in the following sections.

10.2 RANGELAND MANAGEMENT

Landsat offers the prospect of improved management practices for the private stockman and the manager of public rangelands. The following areas of benefit have been identified:

1. Assessing forage availability. The stockman and public land manager must determine when seasonal grazing may commence, the intensity of use, the requirements for supplemental feed and the time for removing stock to protect the range from overgrazing. Landsat can be useful in this function, provided that the Thematic Mapper demonstrates good capability for biomass measurement, to within ± 150 pounds per acre (Deering, 1976).

2. Deciding stocking levels for planning purposes. The private stockman and public manager must plan stocking levels well before a grazing season commences, so that bank financing, leases and other management arrangements can be made. This requires assessment of the range's typical carrying capacity, based on surveillance of range productivity over a period of several years. Landsat is well adapted to this.
3. Range improvement decisions. The stockman's primary means for controlling how the stock will utilize the range is by fencing and placement of water holes. Such capital improvements are expensive. The maximum benefit can be obtained only if the pattern of grazing is studied, and the fencing-waterhole layout is carefully planned. Landsat is readily able to show the grazing pattern and areas of over and underutilization of range for this purpose.
4. Detecting 'problem' rangelands. Rangeland that is consistently overgrazed will show a progressive change in species composition — from desirable to less desirable grasses, weeds, and eventually shrubs and bare ground. When this is observed on public lands, shrub clearance, seeding, changes in grazing practices and stock allotments, etc. are called for. When private lands are involved, endeavors should be made by the Soil Conservation Service to make the owner aware of alternatives to consider, and public help that is available. Landsat is useful in detecting these 'problem' range areas, since it can detect significant changes in species composition (Berkeley, 1976).
5. Trepass control. The public land manager is faced with the problem of preventing grazing without a license or beyond the terms of a license — yet he has very few enforcement officers to cover millions of acres. Although Landsat cannot prove a violation, it can be of great use in finding places of likely violations so that the limited enforcement resources can be programmed more efficiently.

10.3 CROP PEST MANAGEMENT

Landsat should provide substantial benefits in crop pest management, based on the enormous quantity of losses — estimated at over \$4 billion in 1973 (ECON, 1974) — and the apparent detectability of pest-related information.

Insufficient work has been done to determine definite satellite capabilities, or the manner of using the information to the growers' best advantage. Investigations, such as the study of the alfalfa weevil at Purdue, are expected to remedy this lack in the near future.

Despite the absence of definitive work at this time it should be possible to determine the areal extent, severity of damage, and rate of movement of the zones of affliction, insofar as the early-phase damage is visible in the plant foliage. It should also be possible to observe vegetation that is under stress from drought or from excessively cool, warm, or moist conditions, and therefore more than usually susceptible to disease.

For the Landsat data to be of maximum utility to growers and agricultural advisors, it should fit into eco-system models that predict the rate of development of pests as a function of the initial insect population levels, plant condition levels, and weather. Whether the Landsat-generated information is processed by a model or furnished directly to growers, it would be useful in determining the nature and timing of control activities.

Benefits from more accurate programming of pest control activities include the following:

1. Minimizing costs of pesticide and costs of application
2. Minimizing the rate of development of resistance to the pesticide
3. Minimizing damage to the natural predators of the target pests
4. Minimizing environmental hazards to humans.

At this state of knowledge, however, the magnitude of the expected benefits cannot be quantified.

10.4 CONSTRUCTION SITING

Landsat's capability for detecting fractures in the earth's surface can produce major benefits in the evaluation and selection of construction sites.

Fractures indicate structural weaknesses that are of great importance in locating power plants, dams, mine tunnels, and roadways.

Nuclear power plants, for example, must be located where there is minimal risk of earth movement. Fractures indicate the danger areas of future earth

movement by showing where the earth movements of hundreds or thousands of years past have been concentrated. Seismic records, which generally extend over only a few decades, are far from adequate for this purpose.

Dams are susceptible not only to earth movements but to underground fissures that may cause undermining, leakage, and structural weakening. Such causes are believed responsible for the Teton Dam failure in Idaho.

Mine tunnels are susceptible to cave-ins, and it is believed that fracture patterns indicate the layouts that may be safest. In 1975 there were 61 fatalities that occurred due to roof collapses of underground mines or high-wall collapses in open pit mines, some of which might have been prevented by improved mine layouts.

Finally, highways are very susceptible to landslides, which frequently follow fracture lines or other signs of instability detectable from a satellite.

Landsat is not unique in its ability to detect fractures in the earth's surface, but it shows some fractures not observable from aircraft — primarily those that are long in extent but very subtly marked. The Thematic Mapper is expected to show many features not already shown by Landsat 1 and 2; SKYLAB, with a very similar resolution shows up to five times as many fractures as Landsat 1 and 2 in the limited areas where good SKYLAB imagery has been available.

In conclusion, the prevention of serious errors in siting of major facilities requires the use of all sources of information. Landsat, with the Thematic Mapper, may be expected to contribute a valuable component of this effort.

10.5 GLOBAL ENVIRONMENTAL MONITORING

Despite major changes at work in the world's environment — changes affecting the atmosphere, the seas, the forests and wildlife habitats of the world — no continuous record today exists to document the changes. Landsat 2 and 3 do not report data for the oceans or for some critical land areas and do not assure continuity of service. Other satellites are restricted in function or location. Only the Landsat Follow-on program offers the completeness and continuity of coverage needed to perform time-series studies on the global environment.

The importance of such studies should be evident. The conversion of the Sahel from grazing land to desert within the last 20 years would have been noted sooner — and preventive measures possibly begun — if Landsat images

had been available. Pollution of the seas is increasing dramatically — as attested by airline pilots and sailing captains — but no record is compiled of the sources, movements, or dispersal of the pollution. Forests are converted to settlements, ranges plowed under, and roads built into virgin tundra, all without records that would help scientists and planners to cope with the problems.

Landsat's value in providing such an archive is incapable of estimation — but one may be sure that it is large, and that the value will compound as the length of the record grows and new uses are found for employing it.

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